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LIFE HISTORY TRAITS OF THE GREENSTRIPED ROCKFISH, *SEBASTES ELONGATUS*

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The life history traits of the greenstriped rockfish, *Sebastes elongatus*, a common scorpaenid inhabiting the west coast of North America from near Cedros Island, Baja California, Mexico to near Chirikof Island, Alaska, USA at depths ranging from 12 to 491 m, are described. Maximum observed size was 430 mm fork length (FL) and 980 g. There is strong sexual dimorphism, with females reaching larger sizes. Age composition and growth were estimated from sectioned sagittal otoliths of 465 fish collected in 1995. Ages ranged from 2 to 46 years. Growth was slow and was best described by the von Bertalanffy growth model. A total of 123 gonads was collected throughout 1995. Greenstriped rockfish are viviparous, reproduce annually, and are determinate spawners. There is a delay between copulation and ova fertilization, during which time sperm is stored in the inter-lamellar tissues of a mature ovary. The gonadosomatic index (GSI) peaked in December for males and in May for females. Parturition occurs in June. The length at 50% maturity was 230 mm FL for males and 210 mm FL for females. The rate of natural mortality (*M*) was estimated to be 0.09 using the maximum age method and 0.15 using the catch curve and GSI methods.

INTRODUCTION

The greenstriped rockfish, *Sebastes elongatus* Ayres 1859, is a small, slender scorpaenoid fish with distinctive olive green striping that inhabits the upper continental slope in the eastern temperate and boreal Pacific Ocean. Unlike most rockfish species, greenstriped rockfish are found over mostly sand and silt bottoms with both low and high relief, but sometimes over hard bottom near loose boulders and rocky offshore reefs (Lamb and Edgell 1986, Love et al. 1990). They are often found in small schools with other congeners of similar size, as well as lone individuals. Benthic juveniles are found in inshore waters (Alverson et al. 1964). Greenstriped rockfish are opportunistic

feeders, with their diet including shrimp, euphausiids, pelagic crabs, herring, smelts, sandlances, isopods, and amphipods (Shaw[1] 1999, Love et al. 2002). The maximum observed fork length (FL) is 430 mm and maximum weight is 980 g (NMFS[2]).

The American Fisheries Society (AFS) recognizes the common name greenstriped rockfish for *Sebastes elongatus*. Other common names include striped and strawberry rockfish and cucumber, poinsettia, serena, reina, and strawberry rockcod (Phillips 1957, Hitz 1965).

This species has been lightly exploited in the past (Fig. 1), but can be captured efficiently with bottom trawls. With the declines in the abundance of other commercial species, its importance is growing as the fishing industry seeks new target species (Bloeser[3] 1999). Landings of greenstriped rockfish have already begun to increase (Fig. 1) and additional information on life history parameters is needed for their management. There is limited information on this species, particularly concerning its distribution, abundance, and other life history parameters.

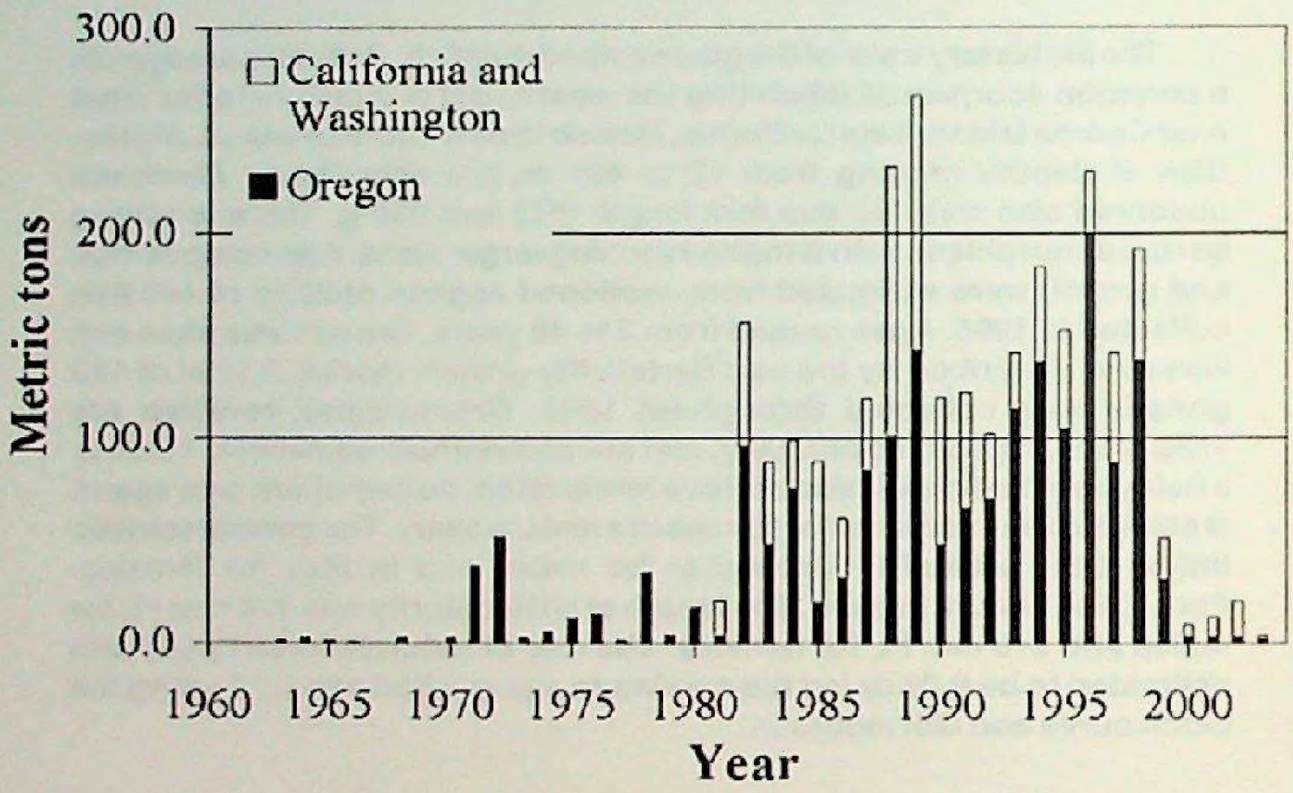

Figure 1: Commercial landings (metric tons) of greenstriped rockfish for California and Washington 1981-2003 and for Oregon 1963-2003. Single species market categories for greenstriped rockfish in California and Washington were not used until 1981. (Source for data: Douglas 1998 and the Pacific Fisheries Information Network)

[1] Shaw, F.R. 1999. Life history traits of four species of rockfish (Genus *Sebastes*). M.S. Thesis, School of Fisheries, University of Washington, Seattle, WA 98115. 178 p.

[2] National Marine Fisheries Service, Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering survey database 1948-2004.

[3] Bloeser, J.A. 1999. Diminishing returns: the status of west coast rockfish. Pacific Marine Conservation Council report, Astoria, Oregon. 94 p.

METHODS

Collections

Greenstriped rockfish (n = 1,924) were taken in research trawls during the National Marine Fisheries Service's 1995 West Coast triennial survey (Wilkins et al.[4] 1998), which extended from Point Conception (34°27'N) to the middle of Vancouver Island (49°00'N). Size frequency compositions, by International North Pacific Fisheries Commission (INPFC) areas, were derived from the fork length (FL) data taken from sampled fish.

The sampling gear used in the 1995 West Coast Triennial Survey was a high opening Nor'eastern bottom trawl constructed of polyethylene mesh and equipped with rubber bobbin roller gear. This trawl has a 27.2 m headrope and a 37.4 m footrope. The body is constructed of 127 mm stretched-mesh polyethylene netting, 89 mm stretched-mesh web in the codend, and a 32 mm stretched-mesh codend liner. The trawl was rigged with three 55-m dandylines (16 mm steel cable) for each wing and fished with a pair of 2.1 * 1.5-m steel V-doors weighing 567 kg each.

Collections were also made from representative samples using standard collection techniques as opportunities were made available from commercial landings at Astoria, Oregon (46°13'N) throughout 1995. Most fish were captured in bottom trawls at locations within a few hours travel from port (near the mouth of the Columbia River). Gonads were collected at a rate of about 15 per month from the commercial landings. Both ovaries and testes were collected for analysis. Gonads were excised, weighed to the nearest tenth of a gram, and preserved in 10% formalin buffered in sodium acetate trihydrate. Standard histological slides were prepared and examined to determine developmental stages. A total of 123 gonads was collected.

For ageing purposes, the sagittae otoliths were collected from randomly selected samples (n = 342) in the survey catches and from all fish in representative collections from the commercial landings (n = 123). Other data collected included sex, fork length to the nearest millimeter, weight to the nearest gram, and gross maturity stage observations. Weights were determined with the stomach emptied. Otoliths were stored in a 50:50 solution of ethanol and water.

Distribution

Existing data sets from NMFS[2] triennial surveys, along with fish collection records of the University of Washington (UW) and Scripps Institution of Oceanography (SIO) were used to describe geographic and depth distributions of this species.

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[4] Wilkins, M.E., M. Zimmermann, and K. L. Weinberg. 1998. The 1995 Pacific West Coast bottom trawl survey of groundfish resources: Estimates of distribution, abundance, and length and age composition. United States Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-89, 138 p. plus Appendices.

Age and Growth

Otoliths were aged using the "break-and-burn method" (Chilton and Beamish 1982). Age readings were taken from the left otolith, unless there was a problem with clarity, in which case the right otolith was used. The broken otolith surface consisted of opaque and translucent (hyaline) zones. Each hyaline zone was considered an annulus. The sulcus region was the preferred area on the otolith for reading ages, but counts were made in at least two regions, if possible, wherever the clarity was best. The opaque nucleus and the first hyaline zone were considered the first year and each following year was represented by an opaque zone followed by a hyaline zone (Bratberg 1956, Westrheim 1973, Six and Horton 1977, Nedreaas[5] 1990). Only annuli that were continuous throughout the otolith were counted. Only completed annuli were counted (e.g., the newly forming opaque zone was not counted until a clearly defined hyaline zone was formed). All ages of fish were assumed to have a 1 January birth date; that is, the age in the first half of the year equaled the number of annuli plus 1 and later in the year when the hyaline zone was evident the age simply equaled the number of annuli. The sample of 465 otoliths was read by two experienced age readers from the Alaska Fisheries Science Center (AFSC) and the author. An experienced age reader from the Oregon Department of Fish and Wildlife re-read a subsample of 20% of the otoliths. Bias was assessed visually using age-bias plots (Compana et al. 1995) and precision was measured with the coefficient of variation (CV) (Chang 1982).

Annular deposition of opaque and translucent zones for greenstriped rockfish has been validated using marginal increment analysis (Love et al. 1990). Marginal increment analysis has also been used to validate ages for other rockfish species (Kimura et al. 1979, Pearson et al. 1991, Pearson 1996). The radiometric aging technique has been used to validate ages for rockfish (Bennett et al. 1982, Campana et al. 1990, Kastelle et al. 2000). The break-and-burn ageing method is now used in most cases (Beamish 1979, Archibald et al. 1981, Wilson[6] 1984, Nichol[7] 1990, Beckmann et al. 1997) and is generally accepted as valid for aging rockfish (MacLellan 1997).

Age-length Relationships

Results from the age determination were used to develop parameters for the von Bertalanffy (1957) growth equation for each sex. The age-length relationship was established by fitting the von Bertalanffy growth model to the data using a weighted

---

[5] Nedreaas, K.H. 1990. Genetic studies and age-determination of northeast Atlantic redfish (Genus *Sebastes*). Dr. Scient. Thesis, University of Bergen, Norway. 181 p.

[6] Wilson, C.D. 1984. The effects of different otolith aging techniques on estimates of growth and mortality for two species of rockfishes, *Sebastes pinniger* and *Sebastes diploproa*. M.S. Thesis, Oregon State University, Corvallis. 107 p.

[7] Nichol, D.G. 1990. Life history examination of darkblotched rockfish (*Sebastes crameri*) off the Oregon coast. M.S. Thesis, Oregon State University, Corvallis, 124 p.

nonlinear regression solved interatively with Excel (Excel Solver, Microsoft Corp.[8] 1998). This model is expressed as:

$$l_t = L_\infty (1 - e^{-K(t-t_0)}) \quad (1)$$

where l_t = length of fish at age t;

L_∞ = theoretical maximum length;

K = growth coefficient;

t = age of fish; and

t_0 = theoretical age at zero length.

Developmental Stages

The developmental stages of the greenstriped rockfish testes and ovaries are summarized in Table 1. The testes classification scheme is a modification of Carrillo and

Table 1: Summary of the gross and cellular classes and cell stages of greenstriped rockfish testes and ovaries. Testes classification follows Carrillo and Zanuy (1977), Gordo (1995) and Agarwal (1996). Ovary classification is a modification of Yamamoto (1956).

Gross testes class	*Cellular testes class*	*Sperm stages present*
Immature	I, II	Ga, Gb
Developing	III, IV, V, VI, VII, VIII, IX	Ga, Gb, Gc, Gd, PSc, SSc, ESd, LSd, ESz
Ripe	X	Ga, ESz, LSz
Spent / Resting	XI	RSz, Ga, Gb, Gc, Gd, PSc, SSc
Gross ovary class	*Cellular ovary class*	*Oocytes stages present*
Immature	I, II, III	Og, CN, EPN, LPN
Vitellogenesis	IV, V, VI, VII, VIII, IX	Og, CN, EPN, LPN, OV, PY, SY, TY, MN, PM
Clear egg	X, XI	Og, CN, EPN, LPN, Mat, Em
Eyed larvae	XI	Og, CN, EPN, LPN, Em
Spent / Resting	XII	REm, EF, Og, CN, EPN, LPN, OV

Abbreviations:

Ga	1° spermatogonia	LSd	late spermatid	Og	oogonia	TY	3° yolk
Gb	2° spermatogonia	ESz	early spermatozoa	CN	chromatin nucleolus	MN	migratory nucleus
Gc	3° spermatogonia	LSz	late spermatozoa	EPN	early perinucleus	PM	prematuration
Gd	4° spermatogonia	RSz	residual spermatozoa	LPN	late perinucleus	Mat	mature
PSc	1° spermatocyte			OV	oil vacuole	Em	embryo
SSc	2° spermatocyte			PY	1° yolk	REm	residual embryo
ESd	early spermatid			SY	2° yolk	EF	Empty follicle

[8] Microsoft Corporation. 1998. EXCEL SOLVER. Microsoft Corporation, Redmond, WA.

Zanuy (1977), Gordo (1995) and Agarwal (1996). The ovary classification follows the scheme first proposed by Yamamoto (1956) for the flounder, *Liopsetta obscura*, with some minor modifications for use in the viviparous *Sebastes*. For embryonic development greenstriped rockfish correspond to the 33 stages set forth by Yamada and Kusakari (1991) for *Sebastes schlegeli* following the model of Oppenheimer (1937) for *Fundulus heteroclitus*. Further detail may be found in Shaw[1] (1999).

Histological Procedures

Testes and ovary samples were excised primarily from the middle portion of the gonads; however, some samples were also taken from the anterior, middle, and posterior portion of the gonad to verify homogeneity in the stage of development. Tissue samples were washed in distilled water, dehydrated in a graded ethanol series, cleared in xylene and embedded in paraffin. Samples were then sliced with a rotary microtome to a thickness of 5 μ and placed on glass slides. Paraffin was removed by passing through a graded ethanol series. The samples were then stained with Harris' haematoxylin, counterstained with eosin (H & E), and then covered.

Oocyte Measurements

The size of the most advanced mode of oocytes was used as a measure of ovary development (Clark 1934). Oocyte and embryo diameters were measured from cross-sections using an ocular micrometer and compound microscope. If embryos were present in the ovary, the long axis of the egg was used for the diameter measurement. If the embryos had hatched, the estimated standard length of the larvae was used. The size of the fifth largest oocyte or embryo was recorded to avoid a situation where the largest oocyte might be an outlier (West 1990). Most of the larger oocytes or embryos in each section were measured to ensure that at least some would have been sliced close to the center where the information on diameter or length would be most accurate.

Natural Mortality (*M*)

Hoenig (1983) described a method whereby the instantaneous rate of M can be predicted from the maximum age found in a given sample for lightly exploited or unexploited stocks, but may overestimate the natural mortality rate in heavily exploited stocks. A regression equation was developed from longevity and mortality data for 134 stocks, in 79 species, and 3 major taxonomic groups (mollusks, fish, and cetaceans). The predictive equation for fish was as follows:

$$\ln(M) = 1.46 - 1.01\ln(t_{max}) \qquad (2)$$

where M = natural mortality;

t_{max} = maximum age in the sample.

The instantaneous rate of M was also estimated from the age composition or "catch curve" (Robson and Chapman 1961). Age was plotted against frequencies and then M was estimated from the descending right limb of the curve using the following model:

$$M = -\ln(T/n + T - 1) \quad (3)$$

where $T = N_1 + 2N_2 + 3N_3 + \ldots;$

$n = N_0 + N_1 + N_2 + \ldots;$

N_t = number of individuals remaining at age t; and

N_0 = arbitrarily chosen to represent the youngest age of full vulnerability.

The gonadosomatic index (GSI) can be used as an indirect method to estimate M (Gunderson 1997). The GSI was calculated as follows:

$$GSI = \frac{W_{gon}}{W_{som}} \quad (4)$$

where GSI = gonadosomatic index;

W_{gon} = wet gonad weight;

W_{som} = wet somatic body weight.

A nonlinear regression model was used to describe the relationship between length and GSI (Gunderson 2003) and is calculated as follows:

$$GSI = eL^f \quad (5)$$

where L = length in centimeters and

e, f = species-specific constants.

To calculate a representative GSI for greenstriped rockfish, the mean length was calculated from females whose lengths were greater than the length at 50% maturity ($L_{0.5}$). The length-GSI relationship was then used to predict the GSI for a mature female of average size in the population. Only fish whose oocytes were at the migratory nucleus developmental stage were used to develop the length-GSI relationship.

Gunderson (1997) found a strong positive correlation between GSI and M ($r^2 = 0.75$) for 28 stocks of fish. The regression model for the relationship was

$$M = 1.79 \times GSI. \quad (6)$$

The variance of this estimate was estimated using the Delta method (Seber 1982, Gunderson 2003).

Length at Maturity

The percentage occurrence of mature fish at length was estimated by fitting a logistic model to the observed proportion of mature fish. The logistic equation was

$$P_x = \frac{1}{1+e^{ax+b}} \qquad (7)$$

where P_x = proportion mature at length x;
x = fork length;
a, b = constants estimated by the model.

Nonlinear regression (Excel Solver, Microsoft Corp.[7] 1998) was used to estimate the constants.

Length-weight Relationship

The relationship between total length and total body weight was represented by the power curve equation:

$$W = aL^b \qquad (8)$$

where W = weight (g);
L = length (mm); and
a, b = constants determined empirically.

The constants (a and b) were estimated using nonlinear regression (Excel Solver, Microsoft Corp.[8] 1998).

RESULTS

Distribution

Adult greenstriped rockfish are found from near Cedros Island, Baja California, Mexico (28°10'N, 115°15'W, Miller and Lea 1972) to near Chirikof Island, Alaska, USA (56°13'N, 155°53'W, NMFS[2]) (Fig. 2). Most of the population is found between northern Baja California, Mexico and Vancouver Island, British Columbia, Canada (NMFS[2], Love et al. 2002).

Adults inhabit depths from 12 m to 491 m (NMFS[2]), while juveniles are found in shallow water (NMFS[2], Love et al. 2002). Greenstriped rockfish are commonly caught in survey bottom trawls between 100 m and 300 m and the center of their bathymetric distribution is between 150m and 200 m (Fig. 3).

Size Composition

The greenstriped rockfish size compositions by INPFC areas and all areas combined are shown in Figure 4. The total (males, females, and unsexed) curve in the entire survey

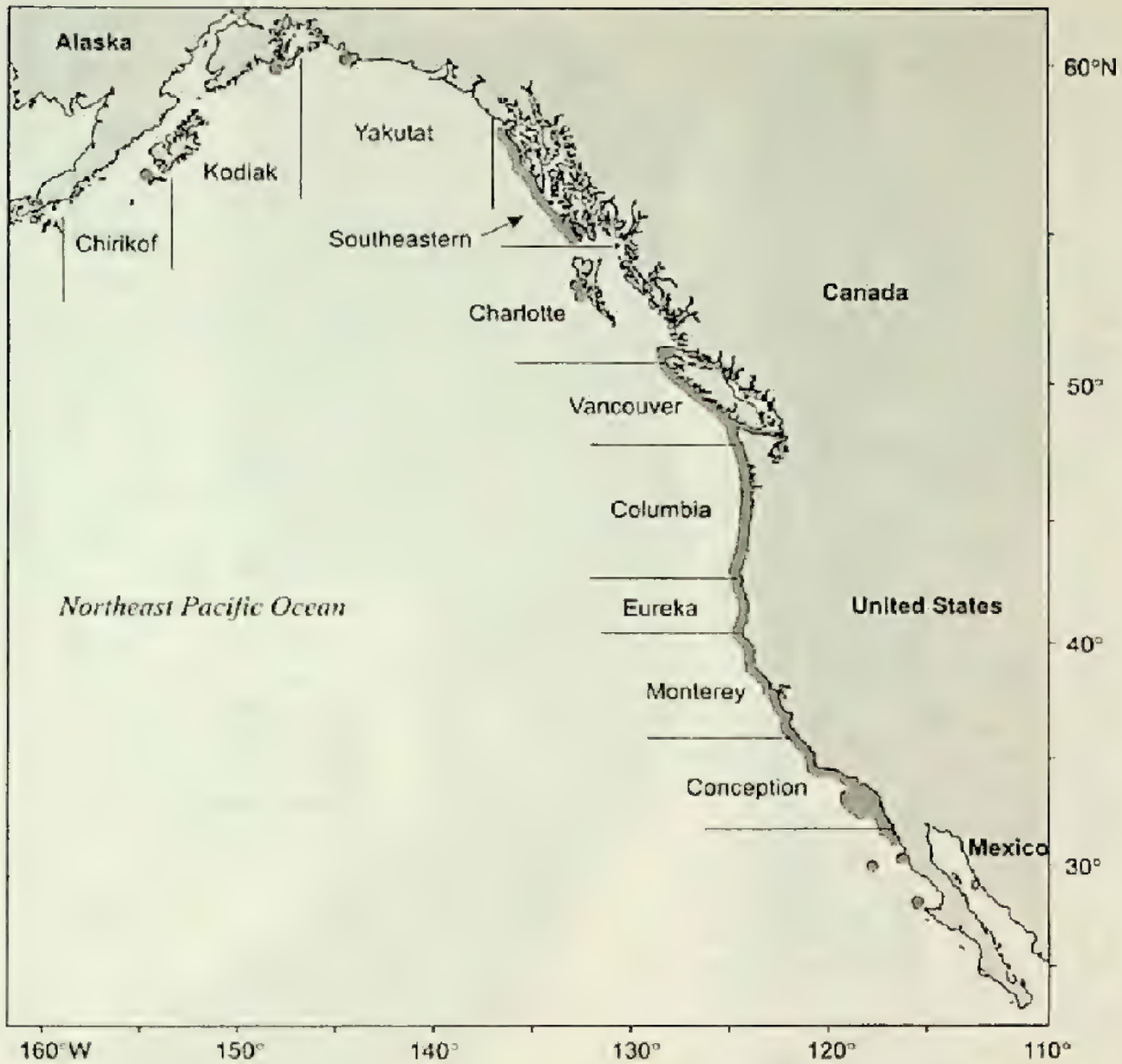

Figure 2: Distribution of greenstriped rockfish based on records in the National Marine Fisheries Service, Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering survey database 1948-2004 and the Scripps Institution of Oceanography Marine Vertebrates Collection, University of California, San Diego.

frame shows a bimodal distribution. The mode at 110 mm is likely made up of 2 year-old fish, based on the length at age data shown in Figure 7. The 210-300 mm FL mode is comprised of cohorts of several age classes.

Age and Growth

In this study the age of greenstriped rockfish ranged from 2 to 46 years (Fig. 5). Independent readings (tests) between different readers indicated that agreement (±1 year) between otolith age readings was 44.4%. Precision (CV) in age estimates was 10.6% between the readings. Little bias occurred as most mean values in the age bias

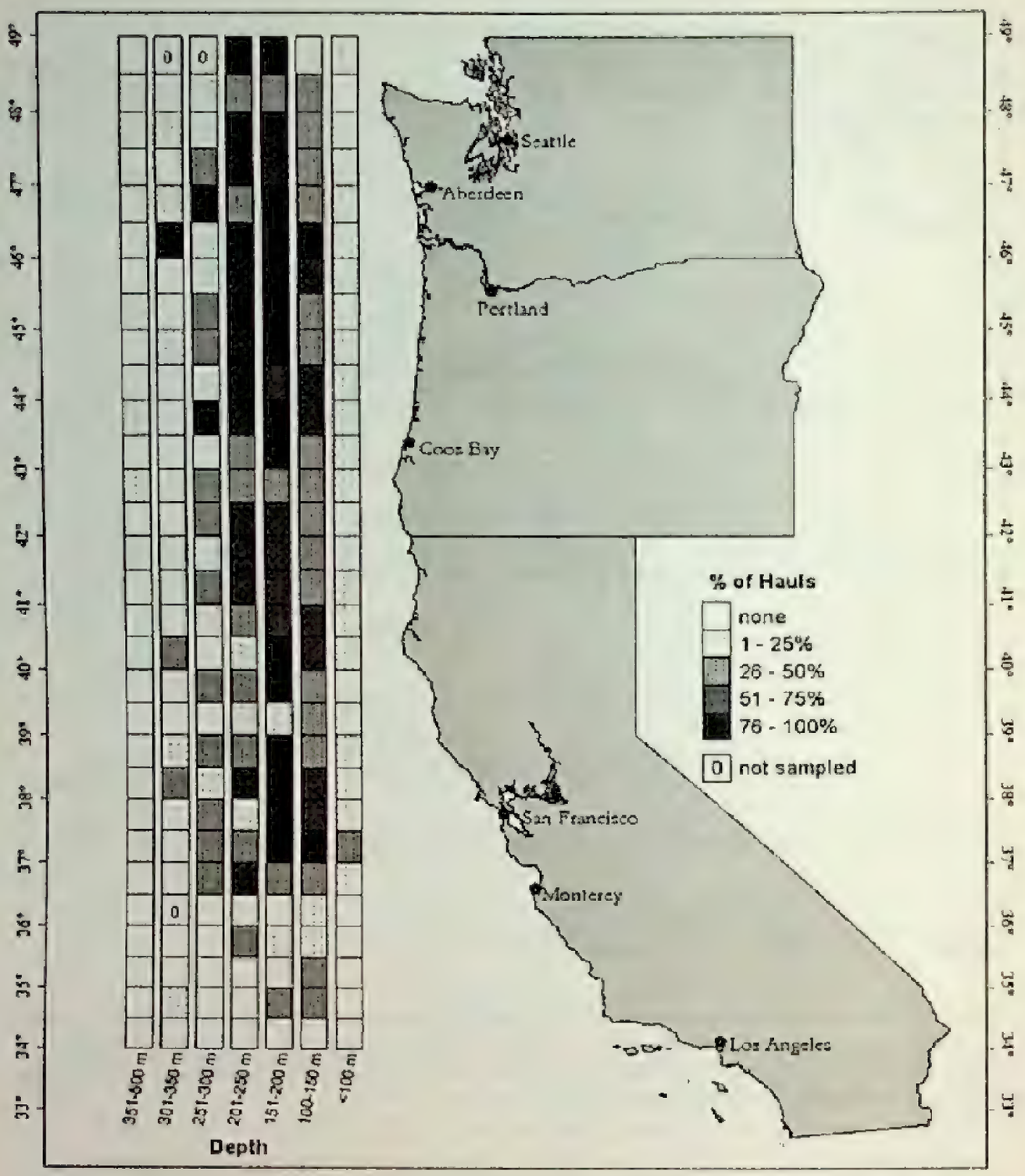

Figure 3: Greenstriped rockfish frequency of occurrence by depth and 30-minute latitude blocks in the National Marine Fisheries Service West Coast triennial surveys 1977-1995.

plot were close to line of agreement (Fig. 6). Mean age for the "test" otoliths (n = 90) was 20.3 years for the original readings and 19.0 years for the test readings.

The age frequency of fish collected in research trawls and commercial trawls for 1995 are shown by sex (Fig. 5). Most of the sampled fish were between 7 and 30 years of age. The most striking difference between the male and female histograms is the

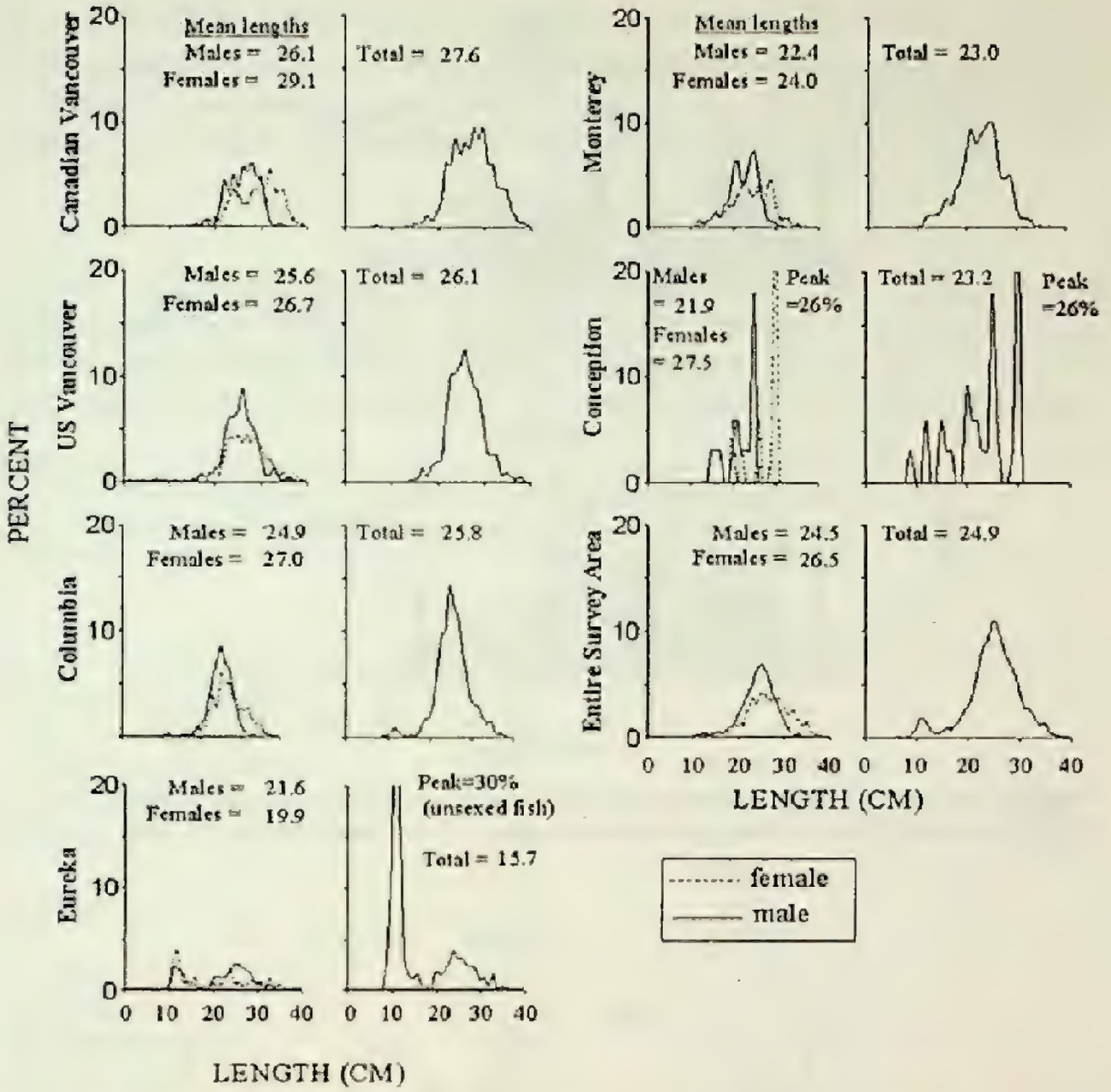

Figure 4: Size composition and weighted mean lengths of greenstriped rockfish by sex and International North Pacific Fisheries Commission area for all depths (55-500 m) from the 1995 National Marine Fisheries Service West Coast triennial survey.

paucity of males in the 14 to 19 age groups. There could be several possibilities for the weakness in the male numbers in these age groups. One explanation is that the females in these age groups were taken in the commercial catches, but the males were not (since the smaller size of the males at a given age may have prevented them from being retained in the commercial catches. Another explanation might be that female rockfish, which are often found in contagious distributions by size, may have been may have been better represented in the random samples due to chance and limited sample sizes.

Parameter estimates for the von Bertalanffy growth model were $L_{\infty} = 301$ mm, $K =$

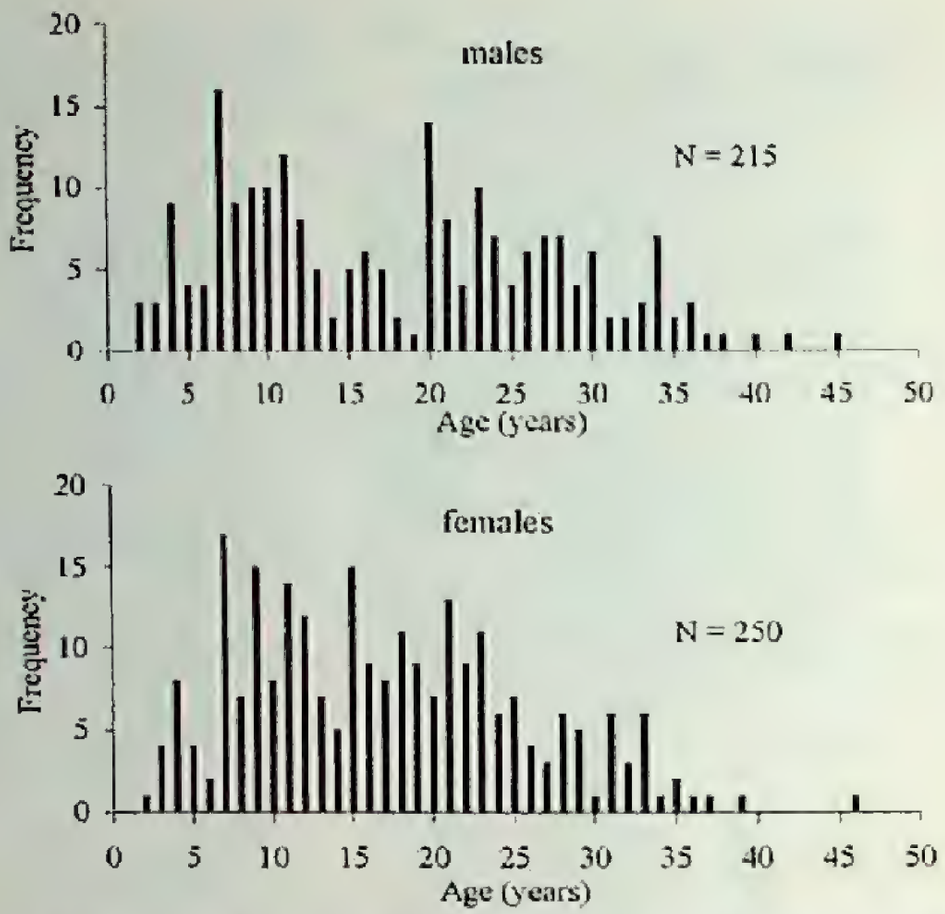

Figure 5: Age-frequencies of male and female greenstriped rockfish taken in 1995 from Oregon market samples (26%) and survey collections taken off Washington, Oregon, and California (74%).

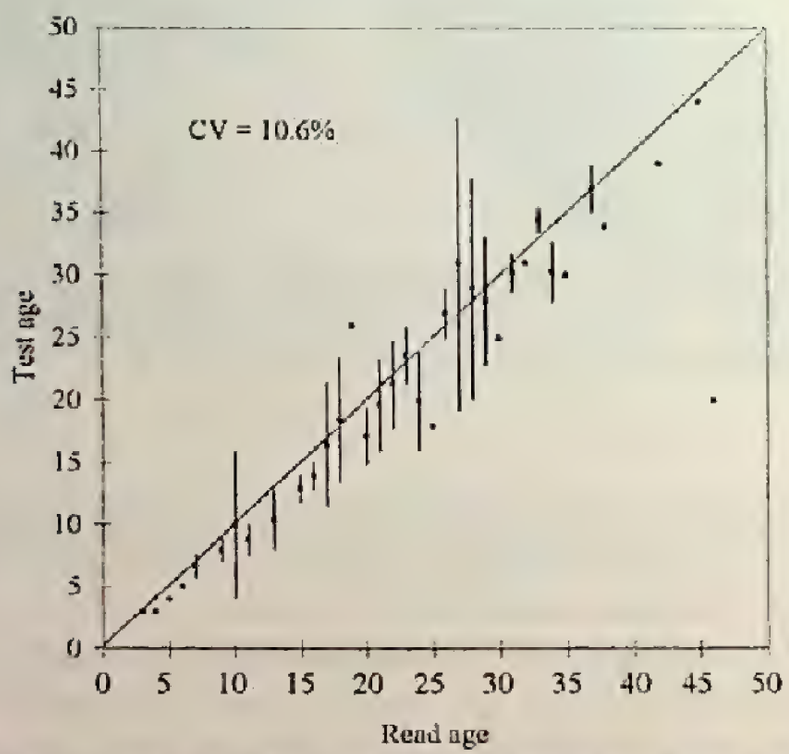

Figure 6: Age bias plot for the comparison of original age readings against the test age readings for greenstriped rockfish. Also included is the 1:1 equivalence line (solid line). Error bars represent the 95% confidence interval about the mean test age for each original reader age.

0.11, t_0 =-3.27 for males and L_∞ =374 mm, K =0.08, t_0 =-3.46 for females (Table 2). The von Bertalanffy growth curves for males and females are shown in Figure 7 along with their respective data points. Growth rates at ages less than 5 are similar for males and females. After age 5, females grow at a faster rate reaching a larger maximum size.

Mortality

Natural mortality estimates based on Hoenig's maximum age, the catch curve, and GSI methods ranged from .09 to .149 (Table 2). The maximum age was 45 years for males and 46 years for females. For the catch curve method the age of full vulnerability to the fishing gear was set at 21 years for both males and females. For the GSI method the mean

Table 2: Summary of life history parameters for greenstriped rockfish from this study unless otherwise noted. Standard errors are in parentheses.

	male	female
Maximum Age (years)	45	46
Maximum Length (mm)[1]	430	400
Maximum Weight (g)[1]	980	915
L_∞ (mm, von Bertalanffy)	300.8	374.5
	(3.5)	(9.8)
K	0.108	0.079
	(0.010)	(0.008)
t_0 (years)	-3.273	-3.465
	(0.700)	(0.889)
$L_{0.5}$ (mm)	230	210
$A_{0.5}$ (years)	10	7
M (maximum age)	0.092	0.090
M (catch curve)	0.142	0.149
	(0.021)	(0.020)
M (GSI)		0.149
		(0.028)
GSI	0.008	0.083
Mating	Dec - Feb	
Parturition	June	
Gestation (days)	40 - 50	
Maximum Depth (m)	491	
Mean Depth (m)	158	
Range North[1]	59° 52'	
Range South[2]	28° 10'	

[1]National Marine Fisheries Service, Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering survey database 1948-2004.
[2]Scripps Institution of Oceanography Marine Vertebrates Collection, University of California, San Diego.

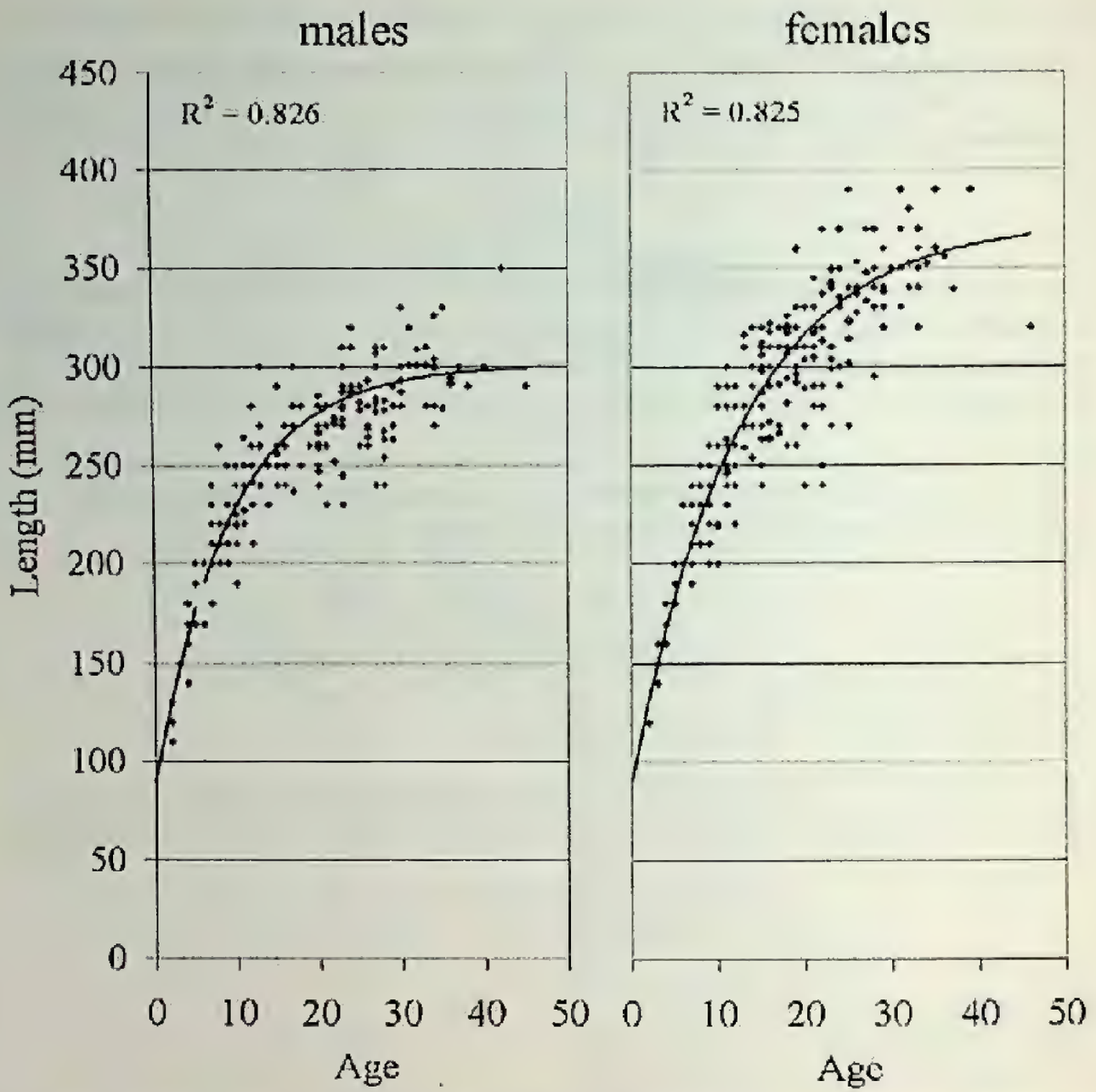

Figure 7: Male and female von Bertalanffy growth curves for greenstriped rockfish taken in 1995 from Oregon market samples (26%) and survey collections taken off Washington, Oregon, and California (74%).

length of mature females was 279.1 mm FL. The scatter in the length-GSI relationship was moderate ($R^2 = 0.44$) and an M of 0.149 was predicted for the average-sized mature female (279.1 mm FL). Estimates of M were similar for the catch curve and GSI methods and lower using the maximum age method.

Reproductive Cycle

Monthly changes in GSI (Fig. 8) and oocyte diameter (Fig. 9) show that greenstriped rockfish reproduce annually and are determinate spawners. There is a delay between copulation and ova fertilization, during which time sperm is stored in the inter-lamellar

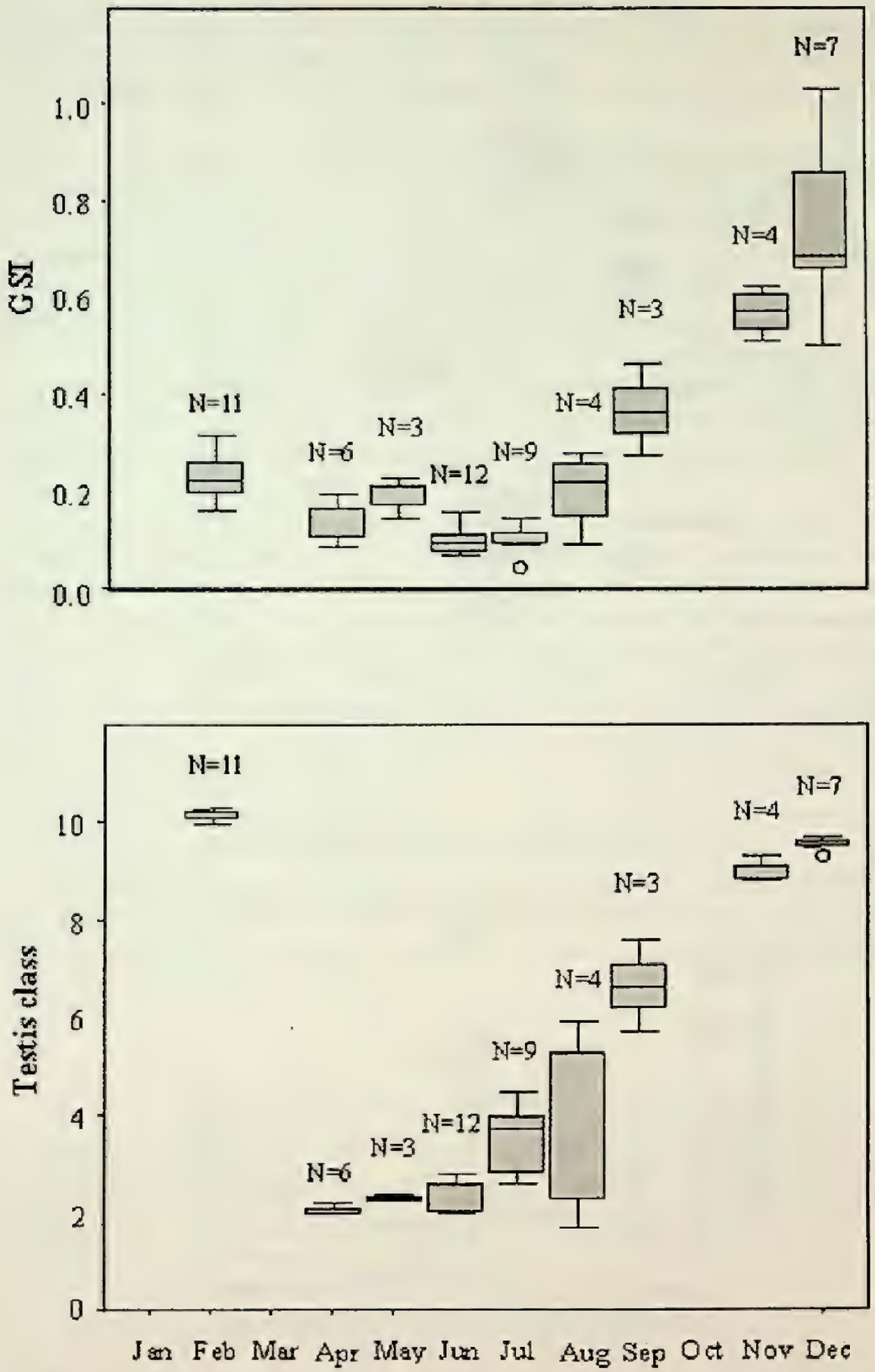

Figure 8: Boxplots of the gonadosomatic index (GSI) and testis class by month for male greenstriped rockfish. The box is the interquartile range. The whiskers are the high and low values excluding outliers (O). The line across the box is the median.

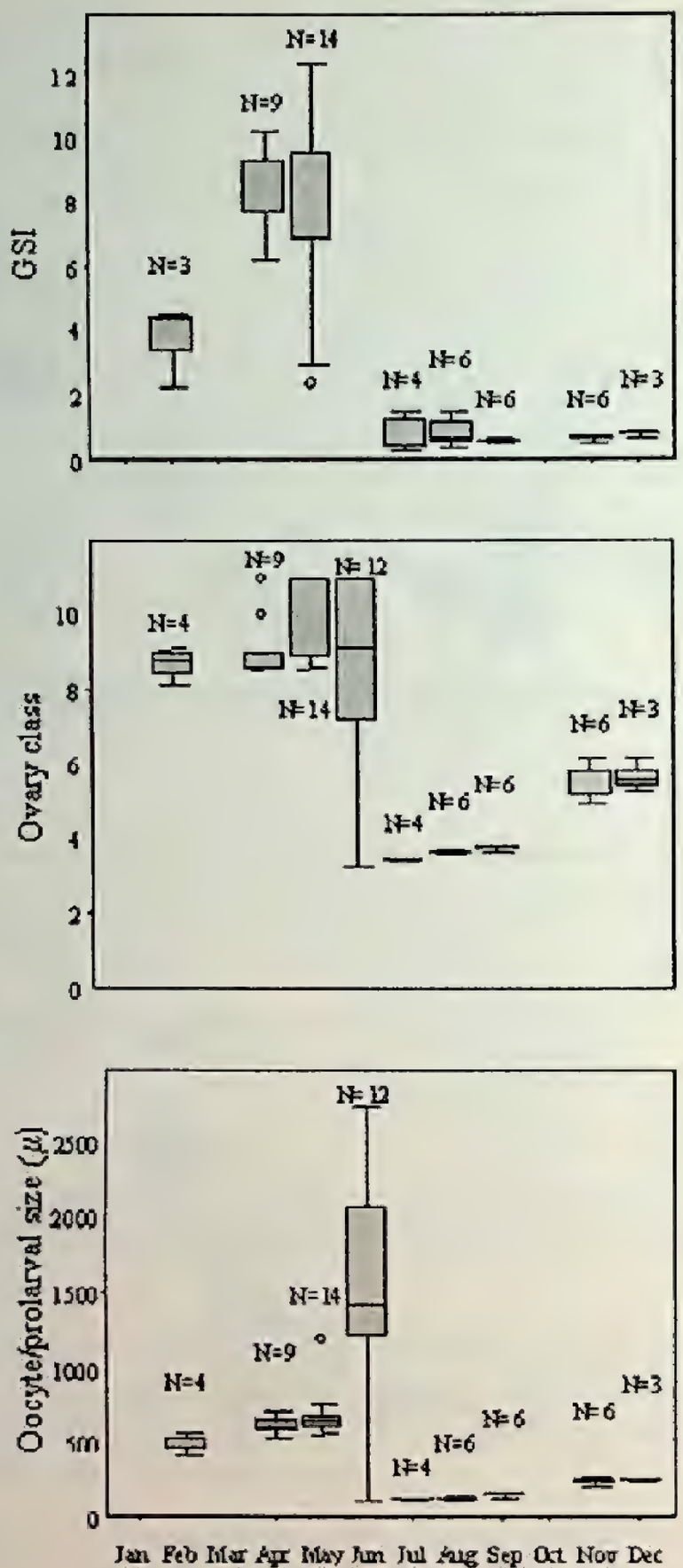

Figure 9: Boxplots of the gonadosomatic index (GSI), ovary class, and oocyte diameter / larval length (m) by month for female greenstriped rockfish. The box is the interquartile range. The whiskers are the high and low values excluding outliers (O). The line across the box is the median.

tissues of a mature ovary (Shaw[1] 1999). For males, the GSI peaked in December, declined rapidly during mating, and continued to decline slowly until July when recovery began. From August until December there was steady increase in the GSI during spermatogenesis (Fig. 8).

The distribution of testicular maturity stages showed spawning beginning in December (late spermatozoa, Class X) and winding down in February (Fig. 8). Residual sperm could commonly be found as late as June and were rarely found as late as August. Spermatogenesis commenced in July. The earliest viable sperm were found in December. Mating probably occurs December through February off Oregon and Washington and sperm is stored until fertilization takes place in April and May.

For females, the GSI peaked in May and fell off rapidly by July (Fig. 9). In June, the ovary walls were so fragile that none of the ovaries remained intact, so GSI values could not be quantified. Mean GSI values remain fairly constant from July to December, although the variance was higher in July and August. A rapid increase in the GSI occurred from January to April.

Ovaries were found to be in the early stage of development (oil vacuole, Class IV) during the summer months (Fig. 9). Progression to later ovary classes occurred from fall to winter. Most ovaries with embryonic development (Class XI) were found in May and June. Spent ovaries were given two classifications: one for the presence of atresia (Class XII) and the other for the most advanced stage of the newly developing oocytes. Only the latter classification is depicted in Figure 9. Spent ovaries were found in July and August. On 20 April 1995, 11% of sampled ovaries contained fertilized eggs. Most ovaries from mature fish contained embryos in early development (stages 10-22) on 9 May and nearly all contained embryos in late development (stages 32-33) on 10 June. No embryos were found on 15 July. The gestation period is estimated to last 40-50 d for greenstriped rockfish based on the developmental observations.

Mean oocyte and fertilized egg size showed a steady increase in size from July to May (Fig. 9). In June there was an abrupt jump in size due to the embryos hatching within the ovary and standard length of larvae being used for the size measurement. Larvae were about 4.5 to 5 mm at parturition.

Maturity

The $L_{0.5}$ for males was 230.4 mm FL (Fig. 10). This corresponded with an age at 50% maturity ($A_{0.5}$) of 10 years based on the von Bertalanffy growth model. For females the $L_{0.5}$ was 209.7 mm FL and the $A_{0.5}$ was 7 years. In both sexes a few fish began to mature at 150 mm FL. 100% maturity was reached at 300 mm FL for males and 280 mm FL for females.

Length-Weight Relationship

The nonlinear regression of total weight on length was described by power curve equation weight = 3.13E-06 * length$^{3.2597}$ (R^2 = 0.981) for males and weight = 3.96E-06 * length$^{3.2145}$ (R^2 = 0.988) for females (Fig. 11). Weights from males and females were

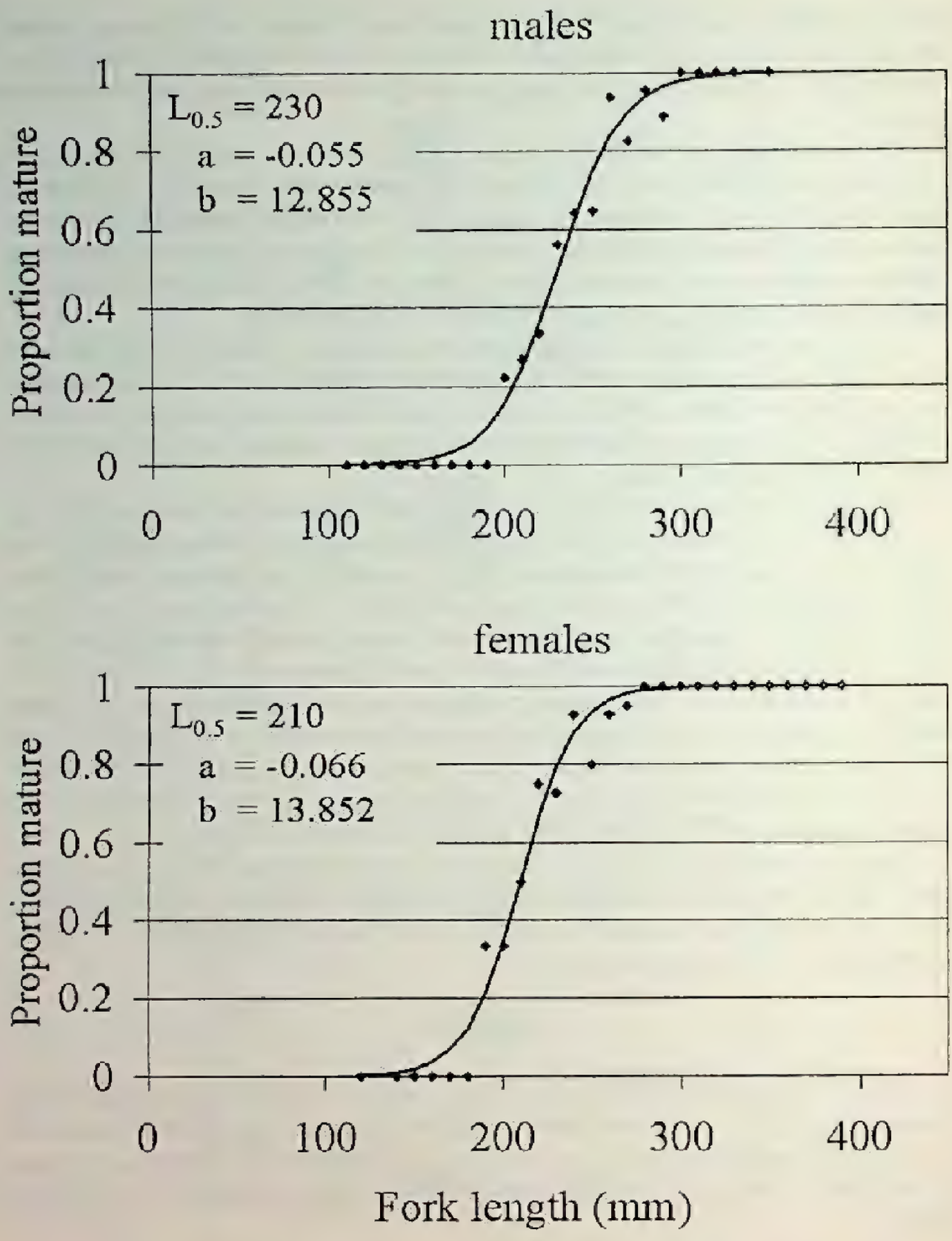

Figure 10: Maturity distributions and logistic curves for male and female greenstriped rockfish taken in 1995 from Oregon market samples and survey collections taken off Washington, Oregon, and California.

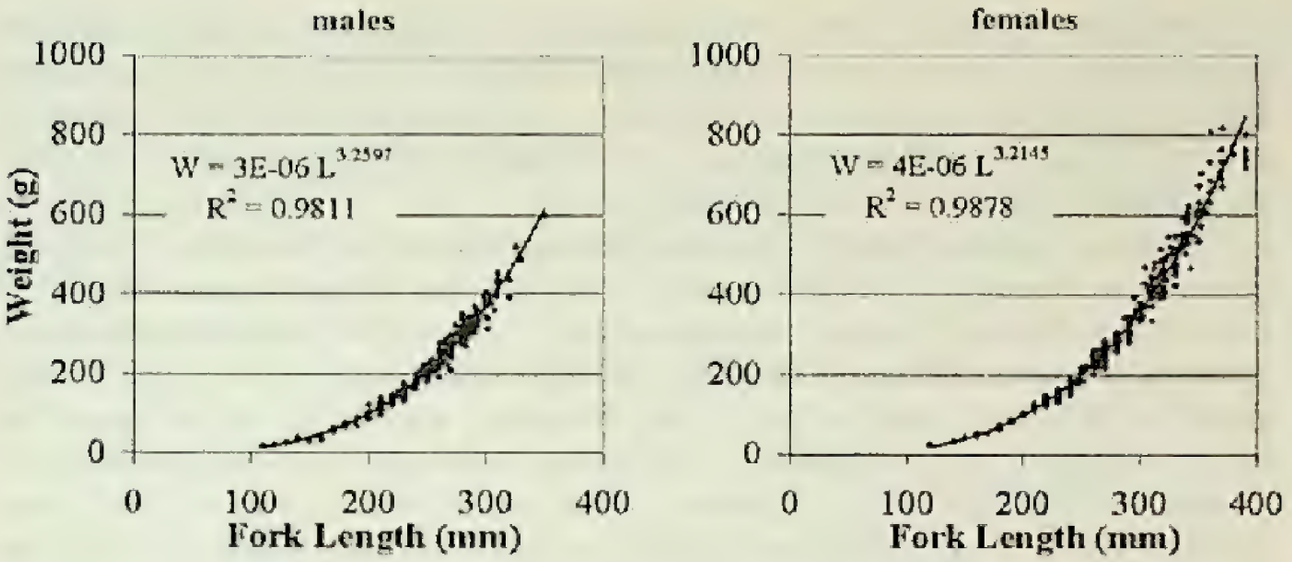

Figure 11: Length-weight relationships of greenstriped rockfish by sex from survey collections (1995) taken off Washington, Oregon, and California.

nearly the same up to about 220 mm FL. At greater lengths females weighed slightly more.

DISCUSSION

Gonadal development in this study was similar to that reported for most northern species of *Sebastes* (Leaman[9] 1988, Nichol[7] 1990, Takahashi et al. 1991). Development is group-synchronous, producing only one brood per year. After ovarian recrudence was well underway, two modes of oocyte stages were found: one mode at resting stage and one synchronized at a vitellogenic or maturation stage. However, in an earlier study on 19 rockfish species in the Southern California Bight, Love et al. (1990) found that greenstriped rockfish produced two broods a year, at least in larger mature females. This was consistent with the phenomenon (Love et al. 1990) where a rockfish species in more northerly waters often spawn one brood (Wylie Echeverria 1987), while the same species southern California form multiple broods (Moser 1967, Love et al. 1990).

The indices of gonadal development (GSI, ovary class, and oocyte diameter in females; GSI and testis class in males) produced similar results except that the peak in the GSI was slightly earlier than the other indices. This was due to the release of spermatozoa or embryos as the spawning season progressed. The gestation period (40-50 d) was similar to estimates for *Sebastes rubrivinctus* (Eigenmann 1892) and *S. paucispinus* (Moser 1967), which were about 1 month in both cases. The estimates of Eigenmann and Moser were based on the continued examination of gonads from a particular population throughout the reproductive season.

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[9] Leaman, B.M. 1988. Reproductive and population biology of Pacific ocean perch (*Sebastes alutus* (Gilbert)). Ph.D. thesis, University of British Columbia, Vancouver, BC. 199 p.

The reproductive development of males and females is offset temporally. The mating season precedes the maturation of the oocytes, imposing the need for sperm storage, which increases the probability that spermatozoa will be available when oocyte maturation has occurred. Copulation precedes oocyte maturation by about 4 months and parturition occurs in June (Table 2).

Gross development classes of the ovary (5) and testes (4) were fewer in number than histological classes and therefore are less precise in reflecting gonad status. Accuracy was also a problem, with immature classes often difficult to differentiate from late spent or resting classes in both sexes. To assess maturity without histological confirmations, gross observations should be made during the mating season (late fall to winter) for males and at the time of parturition (late spring) for females since no misclassifications were made of fish sampled at these times.

Estimates of length at 50% maturity ($L_{0.5}$) in this study were slightly smaller than those for this species taken off southern British Columbia (Harling et al.[10] 1971). The estimates from southern British Columbia were 24 cm FL for males and <23 cm FL for females. In species of rockfish, there is usually a cline in $L_{0.5}$'s (and in maximum body size), with smaller $L_{0.5}$'s to the south and larger $L_{0.5}$'s tending to be found to the north (Wyllie Echeverria 1987, Love et al. 2002). In both the British Columbia study and this study the $L_{0.5}$ was larger for males, while in most other species of rockfish females have a larger $L_{0.5}$ (Wyllie Echeverria 1987)

It should be noted that age data presented relies on collections from both the commercial fishery and research survey. While the mixing of these data can be misleading because the selectivities in the two data sets are very likely to be different, neither data set by itself provides as much detail for the juvenile and adult greenstriped rockfish population than the two data sets combined. The commercial data set is biased towards older individuals because of market selectivity. The research data is biased towards younger fish because adult habitat is hard to sample with the survey trawl (Zimmermann 2003) because of gear requirements for a multi-species survey, whose objectives also include flatfish and hake. The von Bertalanffy age and growth parameter estimates for males and females (Table 2) were very similar to estimates (L_{∞} =296 mm, K =0.12, =-2.73 for males and L_{∞} =373 mm, K =0.10, =-2.36 for females) from greenstriped rockfish in the Southern California Bight (Love et al. 1990) which were collected in a 7.6 meter otter trawl, by hook and line and from commercial catches. If the time and resources were available a survey encompassing the entire depth, habitat and geographic range of the species would provide a better data set.

In the greenstriped rockfish there is strong sexual dimorphism in terms of size, with females ultimately reaching greater lengths and weights. The growth rates of males and females were similar until reaching maturity (ages 7 to 10). After maturity growth slowed in both sexes, with females growing faster than males. The age of both sexes can exceed 45 years. Most fish from commercial catches in this study were between 210 mm and 350 mm FL.

[10] Harling, W.R., M.S. Smith, and N.A. Webb. 1971. Preliminary report on maturity, spawning season and larvae identification of rockfishes (Scorpaenidae) collected during 1970. Fisheries Research Board of Canada Manuscript Report No.1137. 26 p.

This species, like other deep water rockfish, is extremely slow growing compared with most other taxa (Love et al. 1990, Kastelle 2000, Stevens et al. 2004), averaging less than 25 mm growth per year to age 10. After age 10 the mean annual rate is 2.3 mm for males and 3.6 mm for females. Marketable fish, which are 240 mm FL and greater (Douglas 1998), are older than 10 years. While many sizes of fish are sometimes marketable, smaller fish are often discarded. This is especially true of greenstriped rockfish, which is a fusiform species.

ACKNOWLEDGMENTS

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VARIANCE IN SURVIVAL OF YOUNG MULE DEER IN THE SIERRA NEVADA, CALIFORNIA

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Survival rates of young ungulates have not been studied intensively, but are thought to be more variable than those of adults. Survival rates of young potentially are important factors in the dynamics of populations of mule deer, *Odocoileus hemionus*, and other large herbivores. We estimated survival among four cohorts of mule deer from birth to 3 years-of-age that inhabited the Sierra Nevada of eastern California. For males and females combined, survival from birth to 6 months was low ($\bar{x}$ = 27.9 ± 6.8 [SD] %), and differed among cohorts. Annual survival from 6 months to 3 years-of-age was variable (range 80.4 - 90.6%), but survivorship functions did not differ among cohorts. Proportion of mortality of young attributable to predation (55%) was markedly less than reported for adult females elsewhere in the Sierra Nevada (87%), and proportion of mortalities resulting from vehicle collisions (27%) was markedly higher than elsewhere in that range (4%). Our results are consistent with the notion that temporal variation in mortality of young is an important component of variation in the population dynamics of mule deer and beg the question of whether top-down or bottom-up processes regulate populations of those ungulates in arid, unpredictable environments.

INTRODUCTION

Mule deer, *Odocoileus hemionus*, are among the most abundant and conspicuous large mammals in North America. Mule deer are highly prized game animals, are important indicators of ecosystem health (Loft 1998*a*, Kie and Czech 2000, Mackie et al. 2003), and have tremendous economic and aesthetic value (Loft[1] 1998*b*). Moreover, management of mule deer populations can be controversial and result in mistrust of those charged with the conservation and management of that resource (Freddy et al. 2004).

Populations of mule deer fluctuate over time (Mackie et al. 2003), and populations throughout western North America appear to have undergone substantial changes during the past 50 years (Workman and Low 1976, Longhurst et al. 1976, Mackie et al. 2003). Mule deer populations are subject to the influences of nutrient availability, competition with other herbivores, accidents, predation, disease, and climate, and those factors have been subjects of numerous investigations. There is general agreement that no single cause can be invoked to explain the dynamics of mule deer populations (Bleich and Taylor 1998), and causes of contemporary population declines (Mackie et al. 2003) remain speculative and controversial (Gill[2] 2001). Indeed, specific, detailed, investigations are required to evaluate factors that may regulate populations of those large herbivores (Hornocker 1976, Knowlton 1976, Connolly 1981, Mackie et al. 2003).

Temporal variation in survival is an important fitness component among large herbivores (Gaillard et al. 2000), and is an important factor in the population dynamics of mule deer and white-tailed deer, *Odocoileus virginianus* (Short 1979). Four demographic parameters (juvenile survival, fecundity of young females, fecundity of adult females, and adult survival) can be expected to change with shifts in population density (Eberhardt 1977, Gaillard et al. 2000). Among those parameters, variation in post-weaning survival generally is high; variation is markedly lower, however, for yearling survival among ungulates inhabiting temperate environments (Gaillard et al. 2000), such as those occupied by mule deer. Nevertheless, survival of offspring remains highly variable within and among populations of large herbivores (Gaillard et al. 1998). Because most investigators have not separated survival rates of young animals from those of older adults, there is limited information available on variation for that fitness component (Gaillard et al. 2000).

Adult female survival generally is characterized by high survivorship and low yearly variation, regardless of causes of mortality (Gaillard et al. 2000). Because of the paucity of information related to factors affecting the demographics of mule deer from post-weaning through yearling stages, we examined survivorship and cause-specific

[1]Loft, E. R. (editor). 1998*b*. An assessment of mule and black-tailed deer habitats and populations in California. California Department of Fish and Game, U.S. Bureau of Land Management, and U.S. Forest Service, Sacramento, California, USA.

[2]Gill, R. B. 2001. Declining mule deer populations in Colorado: reasons and responses. Colorado Division of Wildlife Special Report 77, Denver, Colorado, USA.

mortality for young up to 3 years-of-age. Our purpose was to estimate survival rates of young mule deer and test the hypotheses that survival rates differ (1) between males and females within years, and (2) among young born during different years for animals from 6 months to 3 years-of-age. Finally, we report causes of mortality for animals that died during our investigation.

STUDY AREA

We conducted research on a population of mule deer that inhabited Round Valley (37°24'N, 118°34'W), Inyo and Mono counties, California, during winter (Kucera[3] 1988), but that migrated long distances northward and westward to summer ranges (Kucera 1992). Mule deer occurred in Round Valley from approximately 15 October through 15 May, and inhabited summer ranges the remainder of the year.

Round Valley is extremely arid as a result of the rainshadow cast by the Sierra Nevada, an immense mountain range oriented in a north-south direction that forms the western boundary of that winter range. Mean (± SD) annual precipitation at the Bishop airport (37°22'N, 118°25'W; 1,340 m) is 13.3 (± 7.0) cm, and approximately 75% of total precipitation occurs between November and March (Fig. 1); potential evapotranspiration in Round Valley is 66.8 cm (Kucera 1992). January is the coldest month ($\bar{x}$ = 0.9 [± 2.6] °C), and night-time temperatures frequently are < -15° C during winter (Kucera 1992). Climatological conditions in Round Valley are similar to those on other winter ranges occupied by mule deer in the eastern Sierra Nevada (Bleich and Taylor 1998).

Vegetation in Round Valley is representative of the western Great Basin, and conforms to the sagebrush belt described by Storer and Usinger (1968); dominant shrubs that figure importantly in mule deer ecology during winter include bitterbrush, *Purshia glandulosa*; big sagebrush, *Artemisia tridentata*; blackbrush, *Coleogyne ramosissima*; desert peach, *Prunus andersonii*; and rabbitbrush, *Chrysothamnus nauseosum* (Kucera[3] 1988, Kucera 1992, Kucera 1997; Pierce et al. 2000*a*, Pierce et al. 2000*b*, Pierce et al. 2004).

Summer ranges occur on both sides of the Sierra crest at elevations from 2,200 to >3,600 m (Kucera[3] 1988). Vegetation zones (Storer and Usinger 1968) on summer ranges include the sagebrush; Jeffrey pine, *Pinus jeffreyi*; lodgepole pine, *Pinus murryana* - red fir, *Abies magnifica*; subalpine; and alpine belts (Kucera 1992). Summer ranges west of the Sierra crest are more mesic than the Round Valley winter range (Fig. 1), and average annual precipitation at Huntington Lake, California (37°22'N, 119°13'W; 2,260 m) near the center of the summer range is 101.2 (± 38.3) cm. Mean annual temperature at Huntington Lake (7.1 [± 1.0] °C) is substantially lower than at Bishop (13.3 [± 0.5] °C).

Use of winter range by livestock is light and occurs in Round Valley largely when deer are not present. Livestock grazing on summer ranges varies from none in remote areas to heavy in easily accessible areas east of the Sierra crest (Kucera 1992). Grizzly bears, *Ursus arctos*, which formerly occurred west of the Sierra crest, have been

[3]Kucera, T. E. 1988. Ecology and population dynamics of mule deer in the eastern Sierra Nevada, California. Ph.D. Dissertation, University of California, Berkeley, California, USA.

extirpated (Storer and Tevis 1955), but areas used by migratory mule deer support an otherwise full complement of native carnivores including mountain lions, *Puma concolor*, coyotes, *Canis latrans*, and bobcats, *Lynx rufus* (Pierce et al. 2000*a*, Pierce et al. 2000*b*). Black bears, *Ursus americanus*, are common on summer ranges west of the Sierra crest, but are encountered infrequently in the eastern Sierra Nevada (Wildlife Programs Branch[4] 2004).

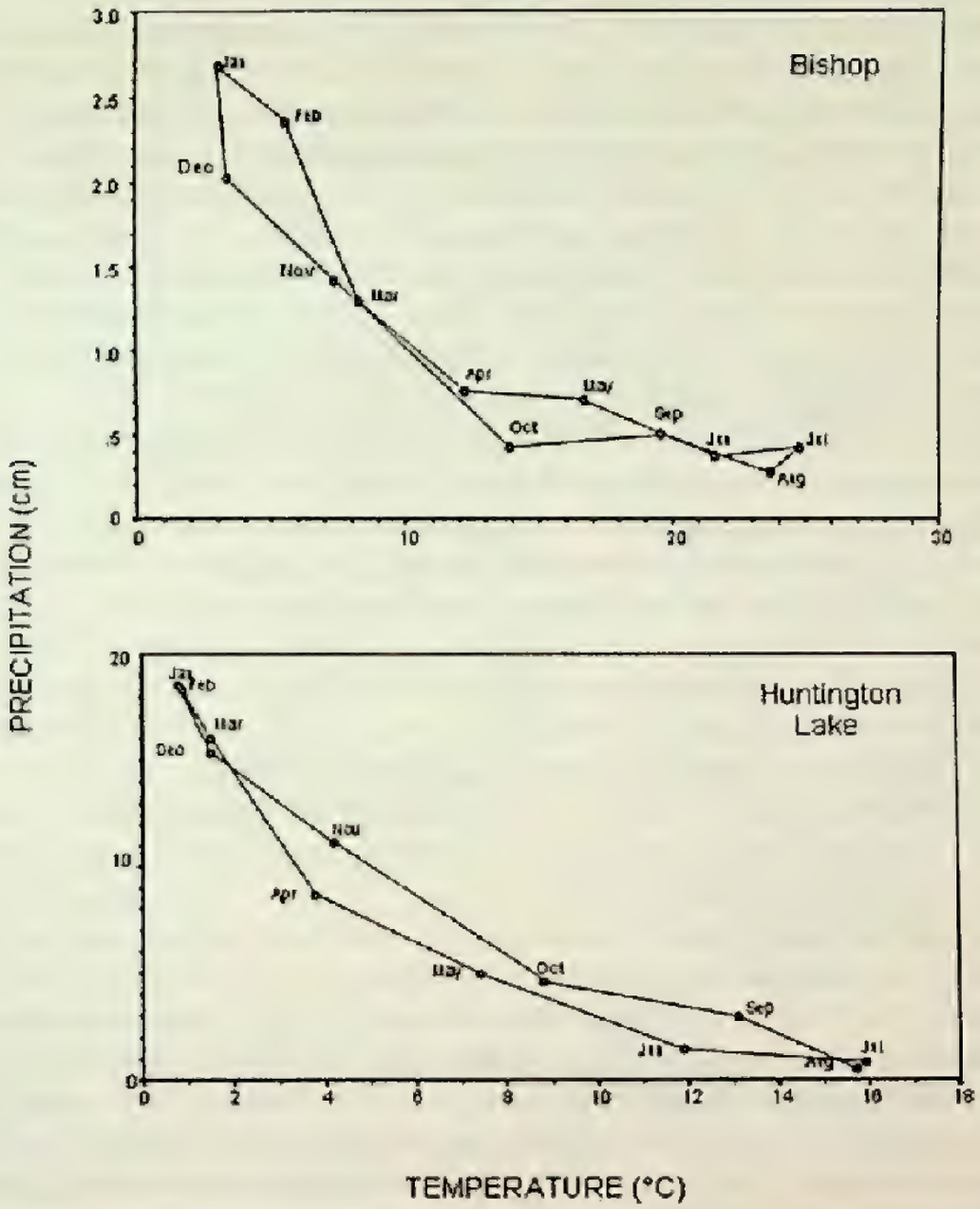

Fig. 1. Climographs (1948 - 2004) for Huntington Lake, California, located near the center of summer ranges used by migratory mule deer west of the Sierra Crest and for Bishop, California, located immediately east of the Round Valley winter range. Scales for both the ordinate and abscissa differ between the two climographs.

[4]Wildlife Programs Branch. 2004. 2003 annual bear take report. California Department of Fish and Game, Sacramento, California, USA (available at: http://www.dfg.ca.gov/hunting/bear/pdfs/beartk2003.pdf).

METHODS

To determine fetal rates during the second trimester of pregnancy, we performed necropsies on females ≥ 1-year-of-age that were randomly selected from the population during March 1993-1996 (Kucera 1997). We used those data to estimate population-level birth rates (i.e., the number of young expected to be born/100 females for each birth cohort).

We used a hand-held net gun (Krausman et al. 1985) to capture mule deer fawns (young-of-the-year, 6-8 months-of-age) in Round Valley. We distributed our capture efforts across the winter range (Pierce et al. 2000*a*, Pierce et al. 2000*b*, Pierce et al. 2004) to ensure that collars were distributed homogeneously across the winter range, and not concentrated in any particular area. Each year, we captured male and female fawns and placed expandable collars that incorporated a mortality sensor (Bleich and Pierce 1999) on them in approximately equal proportions. Fawns were captured during January and March 1994-1997; during 1994-1996, fawns also were captured in March to bring the marked cohort back to the total number collared 2 months earlier. In 1997, logistical constraints dictated that animals were captured only in March.

We monitored the status of each collared deer from the ground on a daily basis from 15 October through 15 May (winter), then every other week using aerial telemetry the remainder of the year (summer). When we received a mortality signal during winter we attempted to locate the animal immediately (almost always within 24 hours) to ascertain date and cause of death. During summer, we attempted to locate the dead animal as quickly as possible, and again determined cause of death. Animals for which date of death could not be ascertained were assigned a date midway between when they were last known to have been alive and when the mortality signal was first detected (Bleich and Taylor 1998). We recorded sources of mortality as species-specific predation, other natural causes, anthropogenic causes, or undetermined. For animals killed by predators, we used the criteria of Shaw (1983) or Woolsey (1985), or relied on our own experience, to identify the species responsible.

We calculated confidence intervals for the number of expected births and for estimates of "recruitment" at 6 months-of-age following the method of Riney (1956). We estimated early survival of fawns for each cohort by dividing the results of aerial surveys conducted in January following their birth (when those young deer were approximately 6 months old, and expressed as young/100 females) by the expected birth rates (expressed as neonates/100 females) and multiplying by 100. We used *G*-tests (Zar 1984) to compare fetal rates among years for females sampled during March, to compare recruitment rates the following January, and to determine if differences existed in proportion of mortalities between males and females by season. We used a goodness-of-fit test (Zar 1984) to determine if proportion of deaths during summer and winter differed from expectation. We used the Kaplan-Meier (1958) procedure, as modified by Pollock et al. (1989) for staggered entry of telemetered animals, to determine monthly and annual survival rates (Bleich and Taylor 1998). To compare survivorship functions, we used the log-rank test (Cox and Oakes 1984) as modified by Pollock et al. (1989). We calculated the most conservative chi-square statistic presented by

Pollock et al. (1989) to enhance the probability that any differences detected between survivorship functions were real (Bleich and Taylor 1998). We adopted $\alpha = 0.10$ as our threshold for statistical significance.

RESULTS

Fetal rates during March (Table 1) ranged from 147/100 females to 182/100 females, but did not differ among years ($G = 0.237$, $P = 0.971$, $DF = 3$). Recruitment rates during January following the year of birth varied from 35.2 young/100 females to 63.0 young/100 females, and did differ among years ($G = 52.850$, $P < 0.001$, $DF = 3$). Percentage of young expected to be born each year and that survived until 6 months-of-age ranged from 22.6 to 37.0 (Table 1).

Table 1. Expected birth rates and 95% confidence intervals (as estimated from fetal rates during the second trimester of pregnancy), recruitment rates and 95% confidence intervals at 6 months-of-age (as estimated from aerial surveys), and proportion of fawns that survived to 6 months-of-age for offspring born to females that used the Round Valley winter range, Inyo and Mono counties, California, 1993-1996.

Year of birth	Sample size[1]	Expected births/100	Sample size[2]	Young/100 at 6 months	Survival to 6 months (%)
1993	28	156 ± 94	446	35.2 ± 6.5	22.6
1994	25	147 ± 92	468	33.5 ± 6.5	22.8
1995	34	170 ± 96	373	63.0 ± 7.0	37.0
1996	20	182 ± 136	547	53.2 ± 7.7	29.2
Mean ± SD		164 ± 15.4		46.2 ± 14.3	27.9 ± 6.8

[1] Number of females in necropsy sample used to estimate expected births/100 .
[2] Number of females in aerial sample used to estimate young/100 at 6 months-of-age.

We placed radio collars on 109 young mule deer (48 males, 61 females) during January 1994 through March 1997. Juveniles captured in January were ~6 months-of-age, and those captured in March were ~8 months-of-age, assuming a birth date of 1 July (Jones[5] 1954). We monitored those deer for a total of 2,499 telemetry-months; monitoring was terminated on the third birthday (i.e., 1 July following 3 full years of life) of each cohort.

Thirty-three telemetered deer (30.3%) died during our investigation and we determined cause of death for 22 (66.7%) of those individuals. Small sample sizes precluded statistical comparisons of causes of death between males and females within years, or making comparisons among years. Among deer for which cause of death could

[5]Jones, F. L. 1954. The Inyo-Sierra deer herds: a final area report. California Department of Fish and Game, Sacramento, USA.

be determined, mortality factors included predation (by mountain lions, coyotes, and bobcats), drowning, and dystocia (Fig. 2). Human-caused deaths were attributed to legal harvest, poaching, and collisions with vehicles (Fig. 2).

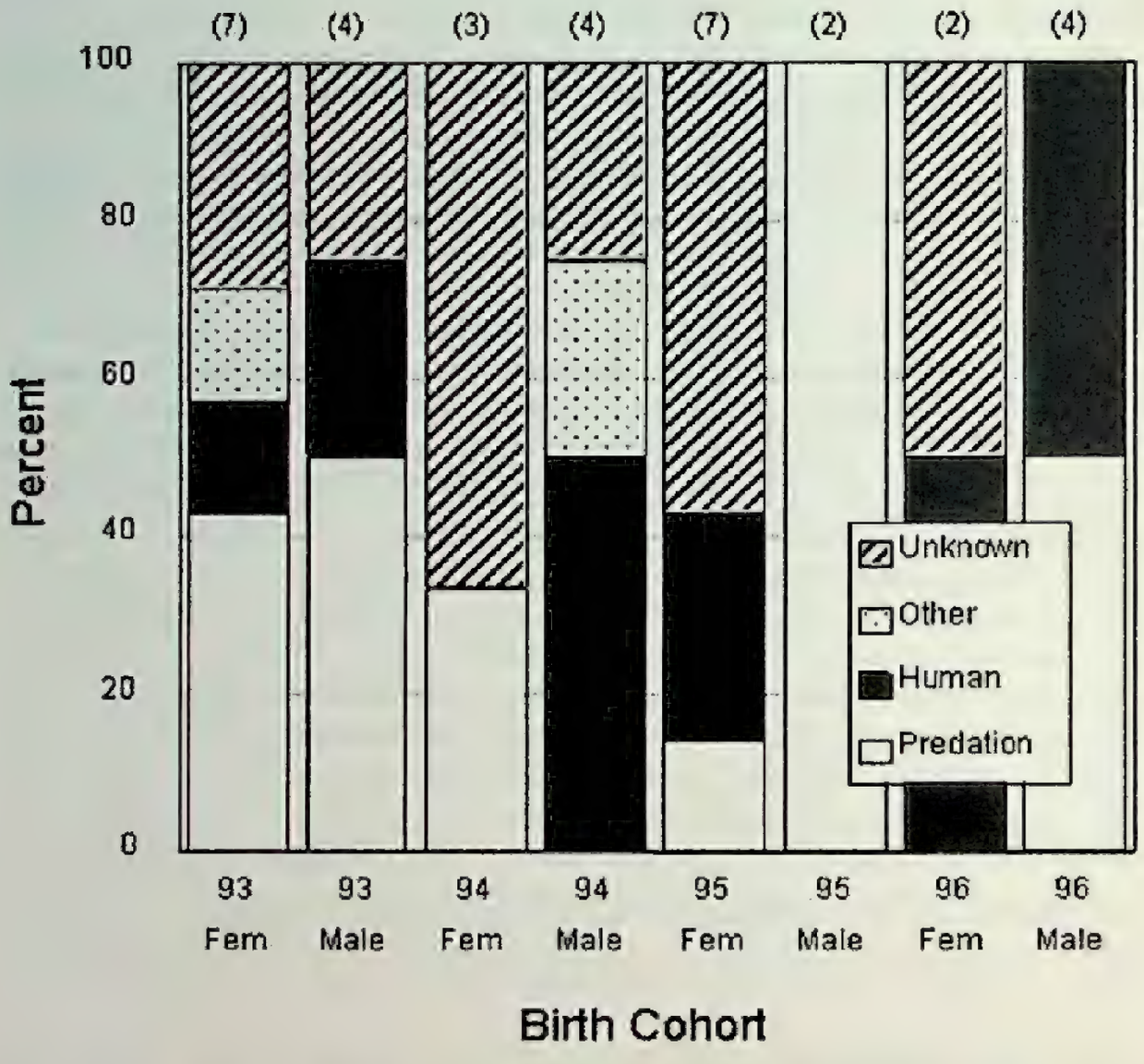

Fig. 2. Proportion of mortality attributed to natural and anthropogenic causes for young mule deer of both sexes and alive at 6 months-of-age. Cause-specific mortality was determined through the third full year of life, terminating with the 3rd birthday for young born to females that wintered in Round Valley, Inyo and Mono counties, California, 1993-1996. Sample sizes are shown parenthetically above the bars.

The proportion of deaths that occurred during summer ($n = 15$) and winter ($n = 18$) did not differ from expected ($G = 0.062$, $P = 0.804$, $DF = 1$), and mortality of males (8 in summer, 6 in winter) and females (7 in summer, 12 in winter) did not differ by season ($G = 1.345$, $P = 0.246$, $DF = 1$). Animals for which cause of death could not be assigned with certainty were distributed about equally between summer ($n = 5$) and winter ($n = 6$).

Survivorship of males and females born during our investigation (Table 2) did not differ from 6 through 36 months-of-age for any cohort; annual survival rates ranged from 0.804 to 0.906 (Table 3). Because no intersexual differences were detected, we combined males with females from each cohort (i.e., animals born in 1993, 1994, 1995, 1996), and compared survivorship among deer born in each of the 4 years; again, no differences existed in survivorship functions (Table 4).

Table 2. Proportions (and standard errors) of young female and male mule deer alive at 6 months-of-age and that remained alive at ages of 1 year, 2 years, and 3 years that were born to females that winter in Round Valley, Inyo and Mono counties, California, 1993-1996. Survivorship was calculated using the method of Kaplan and Meier (1958), as modified for staggered entry of animals by Pollock et al. (1989). No difference ($P > 0.10$) existed between survivorship of female and male fawns for any birth year.

	Year of birth							
	1993		1994		1995		1996	
Age	F	M	F	M	F	M	F	M
1 Year	0.7857	0.9167	0.9333	0.9167	0.8824	0.8182	0.8333	0.9231
	(0.0120)	(0.0058)	(0.0039)	(0.0058)	(0.0061)	(0.0135)	(0.0116)	(0.0055)
2 Years	0.6349	0.7550	0.8711	0.8333	0.7647	0.8182	0.8333	0.8462
	(0.0164)	(0.0156)	(0.0070)	(0.0116)	(0.0106)	(0.0152)	(0.0116)	(0.0100)
3 Years	0.5556	0.6667	0.8089	0.6667	0.5882	0.8182	0.8333	0.8462
	(0.0196)	(0.0185)	(0.0096)	(0.0185)	(0.0142)	(0.0152)	(0.0116)	(0.0184)

Table 3. Sample sizes and estimated survival rates of four cohorts of mule deer (males and females combined) from 6 to 36 months-of-age that were born to females that wintered in Round Valley, Inyo and Mono counties, California, 1993-1996.

Year of birth	Deer (N)	Telemetry-months	Monthly survival	Monthly survival (variance)	Annual survival
1993	26	573	0.982	0.00004	0.804
1994	29	736	0.991	0.000021	0.906
1995	29	610	0.987	0.00002	0.853
1996	25	580	0.990	0.00002	0.886

Table 4. Pairwise comparisons of survivorship functions for young mule deer (males and females combined) born to females that wintered in Round Valley, Inyo and Mono counties, California, 1993-1996. Chi-square statistics are shown above the diagonal; probabilities that survivorship functions differed are shown below the diagonal. For all comparisons, degrees of freedom = 1.

Year of birth	1993	1994	1995	1996
1993	-----	2.052	0.574	0.845
1994	> 0.10	-----	0.462	0.305
1995	> 0.25	> 0.25	-----	0.137
1996	> 0.25	> 0.50	> 0.75	-----

DISCUSSION

We contend that one of the greatest obstacles to better understanding population dynamics of large herbivores is the scarcity of long-term field investigations utilizing marked animals, and that the paucity of results from such investigations limits the use of scientific approaches to conserve those animals. Further, incomplete knowledge of age-specific survival rates hampers efforts to manage populations of large mammals. In an attempt to decrease that void, we addressed the issue of temporal variation in survivorship among four cohorts of mule deer for the initial 3 years of life.

Survival of fawns to 6 months-of-age largely represents "pre-weaning" survival, as defined by Gaillard et al. (2000), and such data are uncommon. We calculated survival rates through the first 6 months of life (Table 1) from ratios of expected birth rates (based on fetal rates estimated for the population during late gestation) and recruitment rates derived from aerial surveys. Thus, our results are subject to potentially large sampling error because ratios can change as a function of changes in the numerator or denominator (McCullough 1994), either of which can be affected by visibility bias (Gaillard et al. 2000) or by heterogeneous distributions across the landscape (Bowyer 1984, Bleich et al. 1997).

Visibility bias in Round Valley likely is minimal because cover is sparse and structure of vegetation is open (Pierce et al. 2004), and adult survival is high (Pierce et al. 2000*b*). Thus, despite the potential shortcomings associated with the use of ratio data, our results are consistent with the widely held notions that most mortality among ungulates occurs during the first months of life (Bowyer et al. 1998, Gaillard et al. 2000), and that mortality rates during that period are substantial (Ricca et al. 2002) and vary temporally (Gaillard et al. 2000). Indeed, estimated mortality during the first 6 months of life ranged from 63.0 to 77.4 % (Table 1), and was comparable to that for other populations of mule deer reported by Salwasser et al. (1978), Hamlin and Mackie[6] (1989), Hamlin et al. (1984),

[6]Hamlin, K. L., and R. J. Mackie. 1989. Mule deer in the Missouri River Breaks, Montana: a study of population dynamics in a fluctuating environment. Montana Department of Fish, Wildlife, and Parks, Helena, Montana, USA.

and Pac et al.[7] (1991).

Body condition of females likely plays a significant role in early survival of offspring (Gaillard et al. 2000, Keech et al. 2000). We were unable to determine causes of death during the pre-weaning period, but annual differences in body condition of females (Kucera 1997, Pierce et al. 2000*b*) indicate maternal condition could have played a role in pre-weaning survival rates. Precipitation is an important factor influencing quantity and quality of vegetation available to herbivores (Noy-Meir 1973, Wehausen and Hansen 1988), both of which can have profound influences on maternal condition and, ultimately, recruitment (Wallmo et al. 1977, Hobbs and Swift 1985). During our study, years characterized by high recruitment followed periods of below-normal (1994) and above-normal (1995) precipitation on winter range, and precipitation on summer range was above normal. Where predators are common, predation is often the primary source of pre-weaning mortality (Linnell et al. 1995), but it is not always independent of maternal care (Gaillard et al. 2000). Clearly, the role of precipitation and its influences on female body condition, juvenile survival and, ultimately, the dynamics of this population warrant further investigation. Moreover, downward trends in habitat quality (perhaps linked to anthropogenic influences including urbanization, or fire suppression, grazing practices, recreational use, and other wildland management strategies; Loft[1] 1998*b*) have important implications for maternal condition and, ultimately, for survival of young. Clearly, the importance of these factors cannot be underestimated.

Among mule deer from 6 months to 3 years-of-age, mortality was divided about evenly between natural and anthropogenic causes (Fig. 2); unfortunately, however, interpretation of these results was confounded by our inability to ascertain cause of death for all animals that died. Proportions of mortality attributable to specific causes differed markedly from those reported by Bleich and Taylor (1998) for mule deer elsewhere in the Sierra Nevada, where predation was the primary cause of death (83%) for adult females, and mountain lions and coyotes were the most important predators. Pierce et al. (2000*b*) reported that mountain lions preyed selectively on adult females and young < 1 year-of-age of both genders in Round Valley. Coyotes did not select young deer, but did prey selectively on adult females (Pierce et al. 2000*b*).

Only male deer are legally hunted in eastern California; when deaths resulting from legal harvest ($n = 2$) were ignored, predation accounted for 55% of mortality in our study. Although predation was an important cause of death for young mule deer, anthropogenic causes were nearly equal in importance (Fig. 2). Differences in the proportion mortalities attributed to predation in Round Valley and other populations in the eastern Sierra Nevada may be attributable to temporal differences in mountain lion densities (which vary with densities of mule deer [Pierce et al. 2000*a*]), as well as the large proportion of road-kills (27%) among deaths we investigated (Fig. 2) when compared to that (4%) reported by Bleich and Taylor (1998). The proportion of deaths attributable to anthropogenic causes among deer in Round Valley can only be expected to increase with destruction of winter ranges and constriction of migration corridors (Kucera and

[7]Pac, D. F., R. J. Mackie, and H. E. Jorgensen. 1991. Mule deer population organization, behavior and dynamics in a Rocky Mountain environment. Montana Department of Fish, Wildlife, and Parks, Helena, Montana, USA.

McCarthy 1988), both of which will increase vehicle traffic.

Survivorship functions for young deer exhibited substantial variation, but did not differ between males and females (Table 2) or among the four cohorts of mule deer (Table 4). Our failure to detect differences may have been a function of sample size. Average monthly survivorship for all cohorts was ≥ 0.982, but annual survivorship ranged from 0.804 to 0.906 (Table 3). Nevertheless, those values are remarkably high when compared to those for adults elsewhere in the eastern Sierra Nevada (0.643 - 0.884; Bleich and Taylor 1998) and other parts of California (0.813 [Schaefer et al. 2000], ~0.60 - 0.80 [Nicholson et al. 1997]). Gaillard et al. (2000) compiled information on age-specific survival of mule deer, and reported that annual survival of "prime age" females ranged from 0.673 (White and Bartmann 1983) to 0.923 (Pojar 1981). When combined with information summarized by Gaillard et al. (2000), our results serve further to illustrate variability in survival rates among young ungulates.

Logistical constraints dictated that we not capture deer in January 1997, and we caught deer only in March of that year. Deer captured in March were, of course, alive the preceding January. Still, it is possible that the cohort of young born in 1996 experienced a higher rate of mortality during January and February 1997 than did the other three cohorts during their initial winters. If that occurred, our estimates of survival for young born in July 1996 would be biased upward. Sex-specific survivorship for young collared during March 1997 was, however, similar to values obtained during other years (Table 2). Thus, we surmise any biases associated with collaring deer in March, rather than January, 1997 were minimal and unlikely to have affected outcomes of our analyses.

Information on age-specific cohort survival is potentially useful in developing conservation and management programs, particularly as they relate to harvest management. Little information is available on post-weaning survival and yearling survival generally is not estimated separately from adult survival (Gaillard et al. 2000). In this paper, we estimated survival rates of mule deer that had achieved an age of 6 months through their 3rd birthday. That period included post-weaning survival, yearling survival, and survival through the 2nd year of life. Survival rates varied among years, but did not differ statistically; nevertheless, failure to detect a statistically significant difference does not undermine the potential biological significance of temporal variation in survival rates of young animals. Survival rates among these cohorts also were similar to those reported for "prime-age females" from throughout the range of mule deer, but markedly higher than survival rates for mule deer from other parts of California and, in particular, from five populations in the eastern Sierra Nevada. Whether interannual differences in climate, regional differences in predation pressure, nutritional differences, anthropogenic influences, or a combination of these were important factors explaining that variation is uncertain, and warrants further inquiry.

Information contained herein can be useful in refining population models, and adds to our general knowledge of variances associated with fitness components (Gaillard et al. 2000). Further, it emphasizes the need for detailed analyses of the relationships between climate, predators, and prey to more fully understand how those factors interact to drive the dynamics of ungulate populations. Cause of death is of general

interest; however, little understanding of the relative importance of mortality factors is gained if mortality is compensatory rather than additive.

Temporal variation in survivorship of young mule deer, when considered in the context of effects of climate, habitat quality, and risk of predation on survival of adult animals (Pierce et al. 2000*a*, 2000*b*, 2004) begs the question of whether top-down or bottom-up processes regulate this deer population. That subject is best addressed over a continuum of ecological conditions involving both prey and predators (Pierce[8] 1999), and emphasizes the importance of long-term investigations an understanding the dynamics of ungulate populations. We concur with Gaillard et al. (2000) that increased cooperation between universities and government agencies is desirable to fully realize the potential of long-term monitoring of marked individuals, and urge administrators to recognize the importance of those collaborative efforts. Indeed, we wonder why resource agencies appear to not recognize the value of long-term data sets and their implications for management of ungulate populations. Ultimately, those endeavors have tremendous value in conserving the complex systems of which large herbivores are such important components.

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RESTORATION EFFORTS AUGMENT RANGE EXTENSION OF A FEDERALLY-THREATENED PLANT, *SUAEDA CALIFORNICA* (S. WATSON 1874)

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INTRODUCTION

California sea-blite, *Suaeda californica* (S. Watson 1874), is a succulent-leaved, perennial subshrub (Fig. 1) found mainly along the margins of coastal salt marshes (Ferren and Schenk 2003). *Suaeda californica* was listed 15 December 1994 as endangered under the U.S. Endangered Species Act. The historic range of this species extended from San Francisco Bay to Morro Bay, San Luis Obispo County, but at the time of its listing as threatened (USFWS 1998), its distribution was considered reduced to sandy soils surrounding Morro Bay estuary (Fig. 2).

In Morro Bay, exotic vegetation, including red gum, *Eucalyptus camaldulensis*, myoporum, *Myoporum laetum*, and iceplant, *Carpobrotus edulis*, has encroached on the narrow band of estuary edge where *S. californica* is found. During spring 2002, the California Department of Parks and Recreation (CDPR) initiated a restoration project aimed at restoring *S. californica* habitat through removal of exotic vegetation along the estuary edge. The expansion of the known range of *S. californica* was also augmented by propagation and introduction. Restoration work, as well as population surveys, occurred throughout Estero Bay, including Morro Bay estuary. Morro Bay plants were used as source material for introductions at various sites.

METHODS

Study Area

Restoration sites (Fig. 3) were locations where introduction was preceded by exotic vegetation removal. At Morro Bay Site A, 0.91 hectare of *C. edulis* was removed and *S. californica* was subsequently planted. Morro Bay Site B involved the excavation of a former unpaved parking lot and restoration of the site to a tidal marsh. At Morro Bay Site C, 10 large *E. camaldulensis* trees and 8 broad *M. laetum* were removed near a natural population of 8 *S. californica* plants located 5 m away, outside the tree canopy. Introduction sites were locations where *S. californica* was introduced without exotic vegetation removal or other site preparation.

Figure 1. Close-up photograph of *Suaeda californica*. Area in photograph is approximately .5 m^2.

Surveys

Presence/absence surveys, a population census, and *S. californica* vegetative cover estimates were conducted along the coastlines of Morro Bay and Estero Bay from Point Buchon to Estero Point. Surveys covered 32 km of coastline and 23 km of estuary edge habitat.

Propagation

Cuttings from source plants in Morro Bay were rooted in a .20 ash/.40 beach sand/ .40 mulch mix. Propagation from cuttings did not utilize hormone treatments. Cuttings were kept in filtered sun under shadecloth. Propagation from seeds involved seed collection, seed drying, and germination in flats of .20 ash/.40 beach sand/.40 mulch mix.

Population Estimates

Due to the overlap of plants, it was difficult to count individuals without causing damage to plants. Therefore, when multiple plants created a large mat, individuals were estimated based on the average size of mature plants. We measured 100 randomly selected plants with >40 cm diameter at random angles (versus greatest diameter) to

Figure 2. The study area is shown with relevant features labeled. Morro Bay is an estuary that opens into Estero Bay. The City of Morro Bay is indicated just north of Morro Bay estuary.

determine the average diameter of mature plants. Plants <40 cm were not measured since these are generally young erect plants that are more readily discerned from other plants within a large mat. The calculated average size of the 100 plants measured was 0.96 m diameter (area=0.72 m^2); a 1-m diameter circle (area=0.78 m^2) was used as a more manageable unit for visual plant number estimation.

In addition, we counted the number of isolated individuals and mats. Mats contain an unknown number of individuals. We estimated an average mat contains four individuals. This average number of individuals within a mat is entirely subjective, as any study of actual plant number would require extensive damage to numerous plants to obtain a meaningful sample size.

Using 0.72-m^2 as an average plant size, the gross area of vegetative coverage of *S. californica* was estimated. We multiplied 0.72 m^2 by the number of 1-m^2 units counted

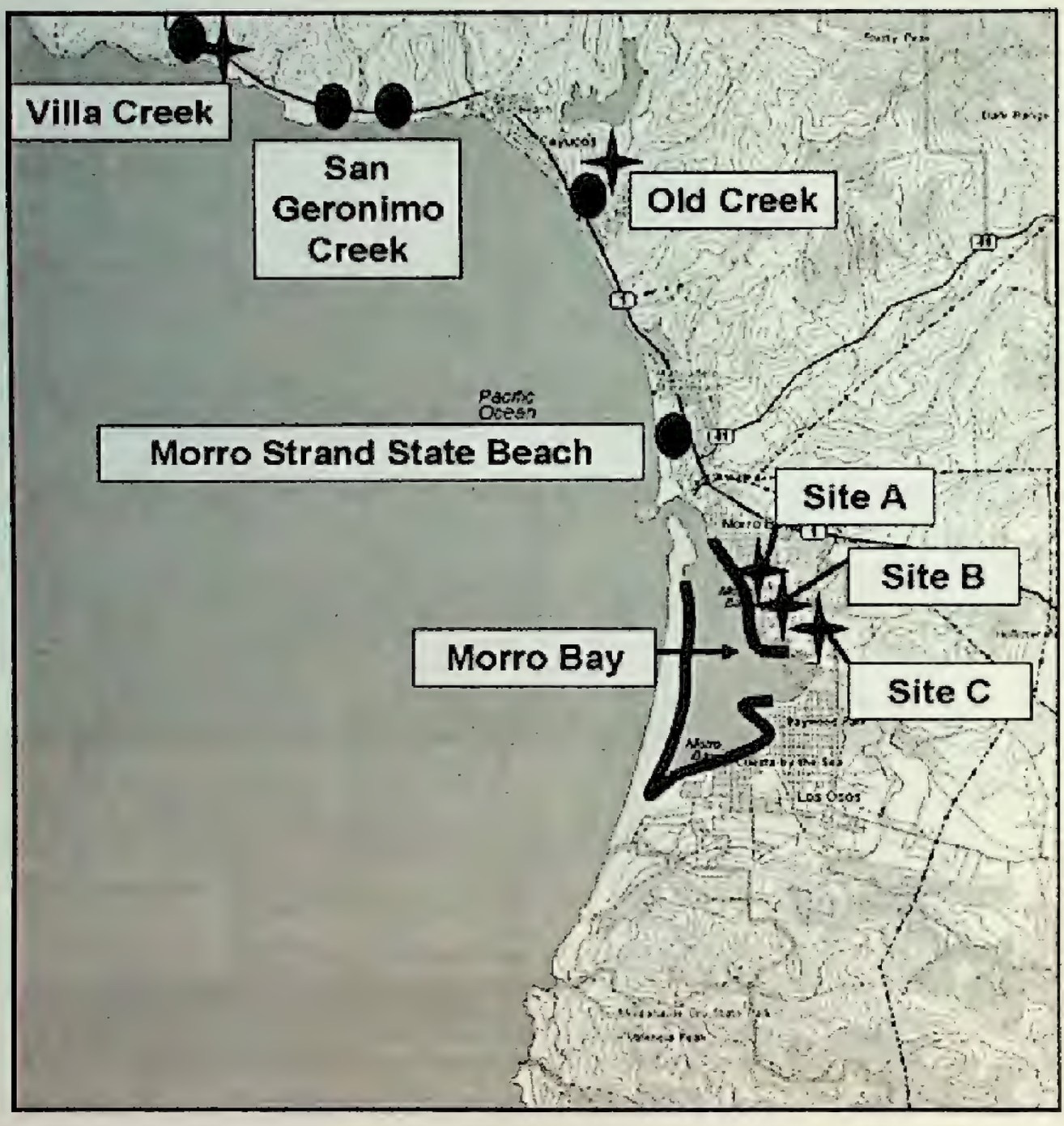

Figure 3. Map of known *Suaeda californica* occurrences within Estero Bay are indicated as black ovals with corresponding names. Stars indicate outplanting sites. Black lines indicate continuous occurrences. San Geronimo Creek includes San Geronimo North and San Geronimo South.

during visual population estimates within mats as well as the number of individual plants counted.

RESULTS

Surveys documented an extended range outside of Morro Bay. The extended range includes new records on clay coastal bluffs (as is typical of *S. taxifolia*), open strand,

and beach dunes. Two newly documented populations at small lagoons could serve as secondary populations to protect against stochastic extinction within Morro Bay.

Natural populations were documented at each site. Populations found at Morro Strand State Beach in 2003-2005 included two plants protected in the swale behind the foredunes, and a total of four plants on the exposed strand. Plants along the strand have since been eliminated by storm waters. Populations at the lagoon mouth at the Old Creek site were completely removed by storm tides in 2002 (five plants), and 2003 (seven plants). In 2004, five of eight plants were removed by storms. As of 2005, 12 plants were found at the lagoon mouth at Old Creek (9 planted, 3 natural). At the San Geronimo Creek North and South locations, 14 of 16 plants have persisted from 2002-2005 in clay soils on coastal bluffs. At Villa Creek, two plants were observed at the creek mouth in 2004 and persisted in 2005.

A population census was conducted in December 2004; two methods were used to estimate the number of *S. californica* individuals within the entire population. An estimate of 3,597 individual plants, including all populations, was calculated using a 1-m diameter circle as a measurement of an individual either alone or within a mat. An estimate of 2,934 plants was obtained by adding the number of isolated plants (1,154) to the number of mats (445) multiplied by an estimated average of four individuals per mat. In conclusion, the low and high estimates give a population range of 2,934 - 3,597 using the two methods of estimating the number of individuals. The gross area of vegetative coverage of *S. californica* was estimated at 2,590 m^2. The Morro Bay estuary occurrences mimic results of the last survey of the estuary edge (Hillaker 1992)[1] (Fig. 3).

Propagation from cuttings has proven 60% successful without treatment by root hormone. Propogules have been successfully planted at introduction sites and have grown to reproductive stage. Propagation from seeds was successful after 6 weeks of soil stratification, though germination was low (<15%). A difference in success between cuttings and seedlings was not calculated, but cuttings were preferred due to less labor investment per plant.

Restoration has resulted in an expanded population at one site within Morro Bay. The *E. camaldulensis* removal work at Morro Bay Site C allowed the population to naturally expand by November 2003, including greater plant size of existing plants and the initiation of four new plants. New plants had grown to 2-m diameter by December 2004 and persisted in 2005 as reproductive plants. Three new plants occurred immediately at or near *E. camaldulensis* stumps, and one new plant occurred at a *M. laetum* stump. By 2004, the former exotic vegetation area was occupied by 20 *S. californica* (8 natural and 12 planted) at reproductive stage.

Restoration included Morro Bay Site B where a former parking lot was removed and excavated to allow tidal influx. By 2004, propagules from cuttings planted 6 months earlier had grown to six mature plants lining the restored tidal area where soil was not compacted. Propogules planted in compacted soils failed. Morro Bay Site A consisted

[1]Hillaker, T.L. 1992. A field research survey: Determining the locality of *Suaeda californica* var. *californica* in Morro Bay, California. Unpublished.

of *C. edulis*, which was removed and replaced with 17 *S. californica*, 8 of which were reproductive in 2005.

Introduction at Old Creek consisted of nine mature *S. californica* established outside the lagoon mouth on raised soils, where tides will not be a threat. At Villa Creek, nine mature plants were planted and grew to reproductive stage; however, storms of 2005 caused ponding and drowned all but one individual.

In general, outplanted material was highly successful (>80% survival to reproductive stage). However, plantings in the compacted disturbed soil portion of Morro Bay Site

Table 1. Location of sites with the number of plants found naturally or planted, and number of planted and naturally occuring individuals surviving as of May 2005. Site types are defined as occurences (O) where natural plants were found, introductions (I) were plants were planted, and restoration (R) where site preparation preceded planting. MSSB=Morro Strand State Beach.

Site	Site type	Material type	Number planted	No. of planted surviving	No. occuring naturally	No. of natural occurences surviving	Coordinates
Villa Cr.	O/I	Cuttings	9	1	2	2	N35 27.63 W120 58.23
San Geronimo Cr. N	O	NA	0	0	13	11	N35 26.87 W120 56.10
San Geronimo Cr. S.	O	NA	0	0	3	3	N35 26.86 W120 55.94
Old Cr.	O/R	Cuttings	9	9	20	3	N35 26.06 W120 53.22
MSSB	O/I	Cuttings	3	1	6	2	Various
Morro Bay Site A	R	Cuttings	17	17	0	NA	N35 20.96 W120 50.64
Morro Bay Site B	R	Cuttings	9	6	0	NA	N35 20.72 W120 50.32
Morro Bay Site C	R	Cuttings	12	12	8	8	N35 20.82 W120 50.17

B, a former parking lot, and a restored airfield at Crissy Field, Golden Gate National Recreation Area, located within San Francisco Bay, (Ward 2004)[2] have failed. In addition, plantings in areas where winter ponding occurs died due to drowning.

DISCUSSION

Pre-project surveys have shown an extended range of *S. californica* in habitats including salt marsh estuary edge, open strand, dune swales, and coastal bluffs. Observations of plant occurrences documented local extirpations by storm events, followed by recolonization the following year. Thus, *S. californica* appears adapted to disturbance from storms.

Soil associations have been expanded to include clay soil. There are few characteristics that distinctly separate *S. californica* and *S. taxifolia*. Plants on clay bluffs were identified as *S. californica*, rather than a northern extension of *S. taxifolia*, based on the following; plants glabrous, vestiture sparse with hairs limited to the margins, calyx lobes glabrous, ovaries without a distal neck-like extension, and predominantly three stigmas (all features consistent with specimens from the main population of *S. californica* at Morro Bay).

Propagation of plants from cuttings has proven successful. Out-planting to augment known populations has proven inexpensive and successful. Out-planting into areas protected against the threat of winter storms, constant water, or compacted soil offers the possibility of establishing secondary populations outside of Morro Bay. Therefore, *S. californica* appears to be a plant whose recovery objectives can be realized at low cost and minimal effort through restoration within the historic range. California Department of Parks and Recreation ownership of much of the suitable habitat between Morro Bay and San Francisco Bay offers promising recovery options.

The removal of exotic vegetation, including *E. camaldulensis*, *M. laetum*, and *C. edulis*, resulted directly in the expansion of *S. californica*. Therefore, exotic vegetation is a threat to this endangered species. The parasitic plant *Cuscuta* sp. occurs on *S. californica*, but does not appear to be a threat.

Despite decimation from storm tides, new plants have grown at Old Creek and at Morro Strand State Beach each year from 2002-2005. No studies have been conducted to examine regeneration rates and seed bank germination after storm events; however, Old Creek and Morro Strand State Beach could serve as study sites for such research.

Current efforts include increasing the size of secondary colonies at the reintroduction sites. In addition, efforts have begun to establish new colonies between Estero Point and San Simeon Point. A re-established colony also exists in San Francisco Bay (Ferren and Schenk 2003) at Heron's Head Park, Port of San Francisco.

Continued efforts should focus on using propagated material to create colonies protected from storm tides outside of Morro Bay. Given the small population of plants within Morro Bay, efforts should be made to create secondary colonies as a plan against

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[2]Ward, A. 2004. Personal communication. Resource Management Department. Golden Gate National Recreation Area.

stochastic extinction. Efforts should focus on the historically documented occurrences within San Luis Obispo County and the greater San Francisco Bay area. Successful introduction at Elkhorn Slough, Monterey Co., could also contribute significantly to recovery of this species.

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A DIET ANALYSIS OF THE BARN OWL, *TYTO ALBA*, IN NORTHEASTERN CALIFORNIA WITH NOTES ON COMPARATIVE METHODOLOGIES

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The diet of the barn owl, *Tyto alba*, has been well documented in areas of the United States as well as other regions throughout the new and old world. According to Ingels[1] (1995), approximately 12 published studies on barn owl diet are available from California. However, only Rudolph (1978) provided data on barn owl diet for areas of California north of Placer County. Results from our investigation will provide the first comparative food habits data from northeastern California and should provide an interesting comparison with data from eastern Great Basin sites (Marti 1988). Additionally, one of our objectives was to investigate the relative importance of post-cranial skeletal element identification in barn owl diet reconstruction. Post-cranial analysis, although time consuming, is essential to diet studies of species such as the great horned owl, *Bubo virginianus*, whose pellets often contain only post-crania or no skeletal remains at all. Unlike barn owls, which generally swallow their prey whole (Yom-Tov and Wool 1997), great horned owls are known to dismember larger prey items such as rabbits and ducks (Marti 1974, Bogiatto et al. 2003), leaving much of the skeleton behind. Unfortunately, species-level identification of small vertebrate taxa using post-crania is often difficult if not impossible, and for that reason, post-crania are often used to corroborate identifications made using cranial elements.

We collected 152 intact pellets from known barn owl roost and nesting sites in and adjacent to Tommy Tucker Cave (TTC), a well known archaeological site (CA-LAS-1) in eastern Lassen County, California (Fig. 1). Eight collections were made between July 1999 and July 2001. This northwestern Great Basin Desert dry cave site is located approximately 3.5 km east of Honey Lake on the western slopes of the Amadee Mountains near the town of Wendell. The entrance to TTC lies at an elevation of 1,276 m, approximately 60 m above the floor of the Honey Lake Valley (Holanda[2] 1998). The valley floor below the cave, which generally receives from 10-40 cm of precipitation annually (Holanda[2] 1998), is dominated by shrubs including big sage, *Artemisia tridentata*, black greasewood, *Sarcobatus vermiculatus*, shad-scale, *Atriplex confertifolia*, horsebrush, *Tetradymia canescens*, rubber rabbitbrush, *Chrysothamnus nauseosus*, and bitterbrush, *Purshia tridentata*; widely scattered Utah juniper, *Juniperus*

[1] Ingels, C. 1995. Summary of California studies analyzing the diet of barn owls. Sustainable Agriculture/Technical Reviews 7: 14-17.

[2] Holanda, K.L. 1998. Understanding artiodactyl body part representation at Tommy Tucker Cave. M.S. Thesis, California State University, Chico. 127pp.

Figure 1. The location of the Tommy Tucker Cave collection site in eastern Lassen County, California.

osteosperma, also occur along the base of the Amadee Mountains. Barn owls and/or barn owl feathers were observed during each of the eight visits in which pellets were collected.

Pellets were collected beneath one known barn owl nest site in TTC, with additional pellet collections from within and beneath three known barn owl perch/roost sites within 20 m of the cave. These features were small, cave-like crevices in the cliffs adjacent to TTC. Upon collection, pellets were individually bagged and labeled prior

to transport back to our lab at California State University, Chico (CSUC). Pellets were dissected in the laboratory, removing all osteological elements as well as the chitinous remains of arthropod exoskeletons. Osteological materials were identified using comparative collections in the CSUC Vertebrate Museum (Department of Biological Sciences) and Zooarchaeology Lab (Department of Anthropology). Arthropod remains were identified using the comparative collection of the primary author.

We attempted to identify all remains to the most specific taxonomic level possible. Materials from each pellet were quantified as the minimum number of individuals (MNI) of each taxon necessary to account for the assemblage of bone and exoskeletal remains (White 1953). For example, a pellet containing three left mandibles and two right mandibles from *Dipodomys ordii* would result in an MNI value of three for that taxon. In order to determine the relative importance of post-cranial vertebrate remains in this diet analysis, one investigator (MJS) calculated MNIs (frequencies) by taxon for each pellet using only crania and mandibles (hereafter referred to as cranial remains). A second investigator (EAB), unaware of our initial results, then calculated MNIs using crania and selected post-cranial elements including humeri, radii, ulnae, femora, tibiae, tibiofibulae, and inominates. We then compared our MNI values for crania alone with those calculated using both crania and post-crania. Because we were unable to identify certain prey items to species (e.g., all birds, some Cricetine rodents, all members of the genus *Peromyscus*, as well as some *Microtus* and *Dipodomys*), comparison of MNI values for those taxa were made at the lowest reliable taxonomic level (class-level for birds, and genus-level for small mammals). In all cases, we used element side (i.e., left or right), size, and age for mammalian remains, based upon the degree of epiphyseal fusion, in calculating our MNI's. Insect MNIs were calculated using identifiable exoskeletal remains such as femora, tibiae, elytra, and mandibles.

Small mammals were the most abundant prey taken by barn owls at TTC, with voles, *Microtus*, western harvest mice, *Reithrodontomys megalotis*, and kangaroo rats, *Dipodomys*, being the most commonly occurring taxa (Table 1). Because the montane vole, *Microtus montanus*, and Ord's kangaroo rat, *Dipodomys ordii*, accounted for all species-level identifications within these two genera (Table 1), it is likely that most if not all unidentified *Microtus* and *Dipodomys* are of these two species. Nevertheless, species-level diagnostics were often lacking, necessitating genus-level identifications. Although our pellet numbers were low relative to other more long-term investigations, our results are consistent with those of other barn owl diet studies in the western U.S. (Foster 1927, Evans and Emlen 1947, Rudolph 1978, Knight and Jackman 1984, Marti 1988, Van Vuren and Moore 1998, and others). The lack of additional prey items and significant changes in the relative proportion of abundant prey taxa following analysis of our final pellet samples suggests that our diet analysis adequately describes the diet of barn owls in the Amadee Mountains. The dominance of *Microtus* in the diet (Table 1) was consistent with results of Marti (1988), who found that *Microtus* accounted for 72% of the total prey items identified (25,330), and which occurred in 100% of 94 pellet collections made at a Great Basin study site in Utah.

As previously mentioned, barn owls generally swallow small vertebrate prey items whole, and therefore, MNI values calculated from cranial and post-cranial remains

Table 1. Prey items identified from barn owl pellets collected in the Amadee Mountains, Lassen County, California, 1994-2000.

Taxon	Frequency (MNI)	% of 451 Prey	% Occurrence in 152 pellets
Mammals			
Sorex	6	1.33	3.95
Sorex trowbridgii	2	0.44	1.32
Unid. *Sorex*	4	0.89	1.97
Scapanus latimanus	3	0.67	1.97
Reithrodontomys megalotis	79	17.52	26.97
Peromyscus	23	5.10	14.47
Neotoma	10	2.22	0.73
Neotoma lepida	4	0.89	2.63
Unid. *Neotoma*	6	1.33	3.29
Rattus	1	0.22	0.66
Microtus	232	51.44	65.13
Microtus montanus	123	27.27	30.26
Unid. *Microtus*	109	24.17	40.79
Thomomys	1	0.22	0.66
Dipodomys	59	13.08	28.29
Dipodomys ordii	18	3.99	8.55
Unid. *Dipodomys*	41	9.09	22.37
Perognathus parvus	29	6.43	13.16
Birds			
Unid. Small birds*	4	0.89	2.63
Insects			
Unid. Coleoptera	4	0.89	1.32

* Small refers to birds ≤ 150g body weight.

should be similar; our results are supportive of this notion. With the exception of one small bird identified from post-cranial remains only, MNI values generated from crania alone were identical to those calculated from crania and post-crania collectively (Table 1), suggesting that cranial analysis alone provides a satisfactory and much less time consuming method for identifying and quantifying the prey of barn owls.

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ECTOPARASITES FOUND ON SALT MARSH HARVEST MICE IN THE NORTHERN SALT MARSHES OF GRIZZLY BAY, CALIFORNIA

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The salt marsh harvest mouse, *Reithrodontomys raviventris* Dixon (Rodentia: Muridae), is listed as an endangered species by both the federal government and the State of California. There are two subspecies - *R. r. halicoetes* in the northern marshes of San Pablo, Grizzly, and Suisun bays, and *R. r. raviventris* in the southern arm of San Francisco Bay (Shellhammer 1982). The salt marsh harvest mouse is a keystone species in tidal and brackish marsh habitats; their populations thrive best in complete, healthy marsh ecosystems and decrease in numbers or experience extirpation in human-altered marshes. Salt marsh harvest mouse populations are negatively affected by the elimination of high marsh and upland habitats that provide refugia during high tides (Shellhammer 1989).

Little is known about ectoparasites on the salt marsh harvest mouse and no flea records are known, although numerous fleas have been recorded from other species of *Reithrodontomys*, particularly *R. megalotis* (e.g., Ford et al. 2004[1]). To address this question, fleas were opportunistically collected from individuals during several trapping sessions in the northern tidal region of Grizzly Bay, Solano County, California (38.16°N, 122.08°W), conducted in July 2004 by the California Department of Fish and Game to monitor mouse populations in salt marsh harvest mouse reserves in the Suisun Marsh.

Mammals were trapped using small (7.6 x 7.6 x 22.8 cm) folding and non-folding Sherman traps (Tallahassee, Florida) set in standard grid formation with 10-m centers.

[1]Ford, P. L., R. A. Fagerlund, D. W. Duszynski, and P. J. Polechla. 2004. Fleas and lice of mammals in New Mexico. United States Department of Agriculture, Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-123, 58 pp.

Traps were placed above the highest high tide line. Harvest mice were identified to species using the identification method described by Fisler (1965) and Shellhammer (1984). Harvest mice were inspected for fleas, which were removed by hand or forceps and stored in screw-thread vials (17 x 60 mm) filled with 70% ethyl alcohol.

Flea specimens were identified as *Orchopeas leucopus* (Baker) (Ceratophyllidae: Ceratophyllinae) at the Plant Pest Diagnostics Laboratory, California Department of Food and Agriculture, Sacramento, California. Voucher specimens (1 male, 1 female) are slide mounted together in Canada balsam, and are housed in the California State Collection of Arthropods, with the following labels: left, "*Orchopeas* / *leucopus* / (Baker, 1904) / det. S.D. Gaimari, 2005 / Vouchers: Clark et al. 2005"; and right, "*Reithrodontomys raviventris* / California: Solano Co. / Grizzly Bay (N tidal region) / 38.16°N, 122.08°W / VII-2004, H. Clark coll. / CDFA PDR# 1333288."

The genus *Orchopeas* has been previously reported from species of *Reithrodontomys*, but not *R. raviventris*. Species of *Orchopeas* seem to be most closely associated with woodrats of the genus *Neotoma* (Cricetidae), but many other hosts, including Muridae, as well as species of Sciuridae and Heteromyidae, are known. *Orchopeas leucopus* is widespread throughout the United States, and is known from all four of these families. In reviewing the literature, Lewis (2000) found references for 76 host species, although the vast majority consisted of only a few species in the genera *Onychomys, Neotoma, Peromyscus*, and *Reithrodontomys*.

The salt marsh harvest mouse has become endangered primarily from destruction and modification of its habitat (Shellhammer 1982, 1989). However, further threats to this species may include parasitic loads present within isolated populations. Threats are twofold. First, the very presence of fleas and other ectoparasites on the salt marsh harvest mouse may compromise their ability to survive due to the nature of parasites, i.e., consuming energy resources from the host, at the disadvantage of the host. Second, ectoparasites, such as fleas, are potential carriers of disease, which may kill the host vertebrate and spread to other populations. This is of particular concern because species of this genus of flea, *Orchopeas*, have been implicated in transmission of epidemic typhus (Sonenshine et al. 1978), and plague (Gage et al. 2000, Davis et al. 2002), including at least one case involving this very species, *O. leucopus* (Holdenried and Morlan 1955). More studies are necessary to determine the effects of parasites and ectoparasite-borne diseases on populations of the endangered salt marsh harvest mouse regarding survivability, physiology, reproduction, and the relationships between flea abundance and host density (Krasnov et al. 2002).

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